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No. 10

GLACIAL AND POST-GLACIAL LAKES IN ONTARIO

BY

A. P. COLEMAN

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LIST OF ILLUSTRATIONS

		PAGE
1.	Section across the Palaeozoic Boundary	7
2.	Escarpment at Hamilton	7
3.	Map of the Laurentian River	11
4.	Map of Lake Algonquin	21
5.	Map of Nipissing Great Lakes	35
6.	Nipissing Beaches at Brulé	37
7.	Map of Lake Ojibway	41
8.	Map of Lake Iroquois	46
9.	Iroquois Shore, Scarborough	47
10.	Iroquois Gravel Bar, East Toronto	48
11.	Map of Admiralty Lake	50
12.	Map of Maximum Marine Invasion	53
13.	Dutch Church in 1900	67
14.	Dutch Church in 1915	67
15.	Map of Shore and Island at Toronto	68

GLACIAL AND POST-GLACIAL LAKES IN ONTARIO

Introduction

The following paper has been prepared in collaboration with the Department of Biology of the University of Toronto, members of the staff of which are now engaged on a plan of investigation of the economic fishery problems of Ontario waters.

Present conditions relating to the existence and distribution of the fishes and other aquatic organisms obviously depend upon the succession of physical changes which have taken place during the past, but in the case of the Great Lakes and related waters the transition is especially important, not only because of the enormous area affected but also because the most significant changes took place in the period immediately preceding the present one, and, centering in the northern continental region, involved great extremes of both temperature and physical modification of the land surface. It is intended to bring together scattered materials on the subject and to put on record a number of observations thus far unpublished; but in the main to outline the Pleistocene history of the lakes as worked out by previous writers such as Gilbert, Spencer, Fairchild, Taylor, Goldthwait, and Johnston. The account of Lakes Iroquois and Ojibway will be taken chiefly from the present writer's previous publications. References will be made to climatic conditions and to the life in the waters and on the shores of these ancient lakes in so far as the evidence permits; and special attention will be given to the comparatively little known lacustrine features of northern Ontario. The southern shores of most of these extinct lakes are almost as well known as those of the existing Great Lakes, but the northeastern parts, where their waters met the waning ice sheet, are still only imperfectly worked out, largely because the region is sparsely settled and to a great extent covered with forests.

The writer has been greatly aided in his work by Professors Bensley, Huntsman, and Clemens, as well as others of the staff in Biology, and wishes to express his appreciation of their assistance. The revision of the names of mollusca mentioned in this report is mainly due to Dr. Frank C. Baker of Urbana, Ill., to whom thanks are due for bringing the nomenclature up to date. Professor A. D. Robertson of the Western University, London, Ontario, also assisted in this respect.

Early Conditions in the Great Lakes Region

The region of the Great Lakes in early Palaeozoic times was a shallow marginal sea skirting the south side of the Canadian Shield where sediments of varying kinds were being deposited. The bottom was gradually sinking, about as fast as the deposits were formed, so that the water remained shallow throughout vast periods of time, including the Cambrian, the Ordovician, and the Silurian. The sediments laid down varied much in character, most of them consisting of mud, a portion of sand and gravel, and another portion, probably formed when the water was deepest, of calcareous materials. When consolidated, the mud formed shale, an easily crumbling rock; the sand turned to sandstone of moderate solidity; and the calcareous matter, shells, corals, etc., gave rise to compact and durable limestones, the thickest being the Niagara or Lockport limestone. Sometime during the later Palaeozoic the region fringing the Precambrian continent ceased to sink, and at length was raised above the sea as a plain gently sloping southwestwards. From that time onward most of the Great Lakes region remained a land surface, only a small part of its eastern side having been briefly submerged at the close of the Ice Age.

During the many millions of years since its elevation above the sea, the Archaean hills to the north and the sedimentary rocks to the south of this region have been ceaselessly attacked by weathering, changes of temperature,

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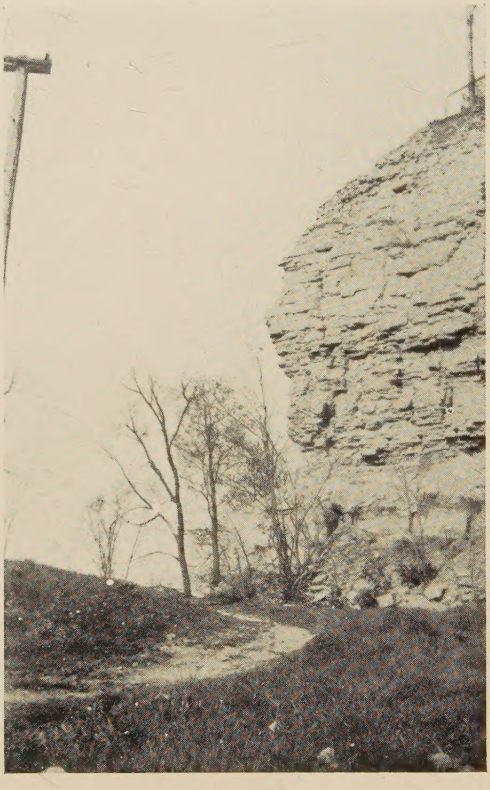

2. Escarpment at Hamilton

and running waters. The crystalline Precambrian rocks have in general resisted these attacks best, and the thick beds of shale have suffered most. The result has been that the sedimentary rocks, which once encroached much farther northwards upon the granites and gneisses of the old Precambrian continent, have, except where protected in some cavity of the ancient surface, been stripped off for a long distance south of the latest shore of the Palaeozoic sea. In this process the shales were removed most rapidly and the limestones resisted best, so that ultimately a broad unsymmetrical trough was carved out with a gently sloping surface of Archaean toward the north and an irregular set of cliffs of the strong Niagara limestone toward the south. The wall was by no means straight, and in places there were two or three lower lines of cliffs between the main elevation and the northern slope of granite and gneiss. This row of

1. Section across the Palaeozoic Boundary

cliffs facing the old land has played an important part in directing the drainage of the region and is still a marked physiographic feature, called in southern Ontario the Niagara escarpment. As the surface above the escarpment follows the gentle dip of the strata southwestward, the arrangement is sometimes called the Niagara Cuesta. The eating back of the sedimentary rocks must not be thought of as due to direct river action but rather to the slow decay of the shales under atmospheric attack, resulting in the undercutting of the cliffs, allowing slices of the overlying limestone to fall, the fragments being removed gradually by solution due to carbonic acid brought down by rain. The escarpment has been caused, then, by differential weathering.

Some time before the beginning of the Glacial period the Great Lakes region stood much higher above the sea than at present, probably at least 1,800 feet. This must have had important effects upon the drainage, steepening the grade of the rivers; and if the uplift was greater in one direction than another, possibly turning the drainage into new directions. There were probably no lakes at this time, the valleys having slope enough to allow all the water to run off; but the directions of flow are not always very certain, and different writers have expressed quite opposite views in regard to the matter.

The Laurentian River

J. W. Spencer, one of the first to discuss the Preglacial rivers, came to the conclusion that the whole region, except the Superior basin, was drained by a predecessor of the St. Lawrence, which he called the Laurentian river, because it flowed on or near the edge of the ancient Laurentian continental mass, reaching the ocean through what is now Cabot straits between Newfoundland and Nova Scotia.[1] Some American writers, on the other hand, consider that the elevation was more to the northeast and that the rivers crossed the escarpment by one or more gaps and joined the Mississippi, finally reaching the Gulf of Mexico. The latter idea has been worked out in detail by Grabau,[2] who thinks the main stream flowed southwestward, crossing the escarpment by a channel at Dundas. Since Grabau's work was done, evidence in the way of well records has been obtained showing that a channel connecting the Upper Lakes with Ontario extends at least to sea level. This and the great depth of the Ontario basin, reaching nearly 500 feet below sea level near its east end, strongly support Spencer's theory, which will be outlined here.

In Preglacial times eastern Canada extended to the edge of the continental shelf, 140 miles beyond the present

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[1]Evolution of the Falls of Niagara, Geol. Sur. Can., 1907, pp. 289, etc.

[2]Bull., N.Y. State Museum, No. 45, Vol. 9, 1901, pp. 37, etc.

southeastern coast of Nova Scotia, and Newfoundland was a part of the mainland. The old river channel then excavated can be followed by soundings to the edge of the enlarged continent, where the shallow water ends, and the bottom descends toward the depths of the sea. By the kindness of Dr. Huntsman the soundings on the chart have been examined, and it is found that the deepest point reaches 335 fathoms and the next deepest, farther up near Bird rock (Magdalen islands), 313 fathoms. The old river valley extended 840 miles beyond Quebec and at the edge of the continent is now from 1,878 feet to 2,010 feet below the sea level. Dr. Spencer made the depth 3,660 feet (611 fathoms), but this sounding is on the slope toward deep water and there are no shallower soundings on each side, so that his interpretation is probably a mistake.

The rest of the great river channel, as given by Dr. Spencer, is mostly above sea level. It begins on his map in the deeper parts of the basins of Lake Michigan and Lake Huron, turns north from about the middle of Lake Huron to Georgian Bay and then bends southeastward along the foot of the escarpment to Barrie. A buried channel extends from Barrie to Toronto, after which the river kept to the deeper south side of the Ontario basin, and finally turned northeast along the present St. Lawrence valley. The buried channel between Georgian Bay and Lake Ontario was inferred by Spencer from wells sunk in drift for a town water supply at Barrie (280 feet) and at Richmond Hill (400 feet). Since his results were published the inference he made has been confirmed and strengthened by several other wells, one at Newmarket reaching 265 feet, another at Bradford reaching 330 feet before striking rock and one on Mr. Page's farm two miles west of Thornhill, where 650 feet of glacial and interglacial materials were passed through before rock was encountered. The well was finally sunk to 1,203 feet in solid rock, ending in Laurentian granite. As the Page well was drilled at a point about 650 feet above the sea, the old channel extends 246 feet below Lake Ontario to present sea level. It is perhaps worth mentioning that

Spencer described this channel as entering the Ontario basin twenty miles east of Toronto, where the Admiralty chart showed a depth of 474 feet, with soundings of no more than 200 feet on each side.[1] This appeared so interesting that some years ago I spent an afternoon sounding across the supposed channel but found no depression in the lake bottom. The sounding of 474 feet was apparently an error for 174 feet. In reality the buried channel comes out to the Ontario basin under the city of Toronto, where drift deposits near the mouth of the Don have been found for a depth of nearly 100 feet below the level of the lake. It is probable that a still deeper drift-filled valley exists to the west to correspond to the sea-level depth of the drift near Thornhill.

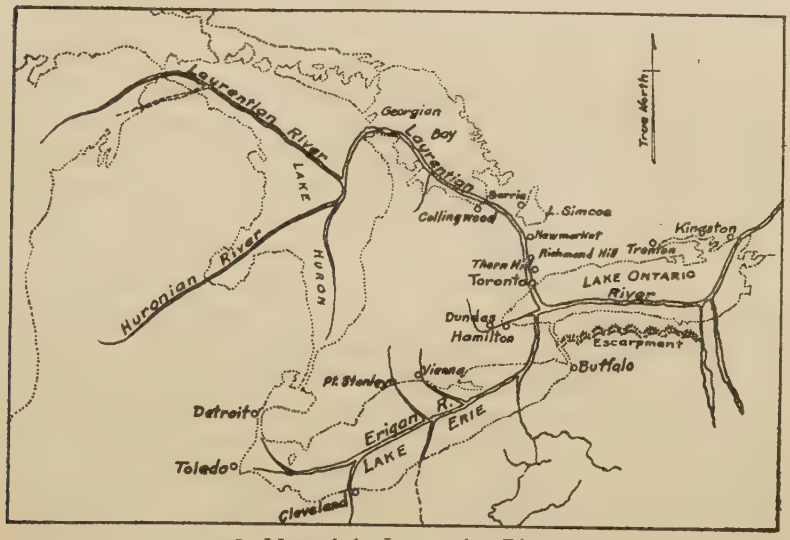
Below Lake Ontario the old channel is lost for a time, since at the present outlet through the Thousand Islands, where for a short distance Archaean rock is encountered connecting the Adirondacks with the old continent, there are no signs of a valley cut into the solid rock such as one would expect a great river to carve in the long Preglacial ages. Probably the original channel is to the southeast of the Thousand Islands and has been overlooked because filled with drift. That the old river flowed to the south of the present St. Lawrence at one place is shown by the fact that water drawn off artificially from the river furnishes an important source of power with a drop of 30 feet at Massena, N.Y. This water is afterward returned to the St. Lawrence at Lake St. Francis, ten miles down stream, and one may suppose that the Preglacial river followed this lower route, avoiding the present Long Sault rapids near Cornwall.

From this point the Laurentian river seems to have occupied the present river valley to Quebec; below which a submerged channel may be traced by soundings, as is mentioned above, till it reaches the edge of the continental platform beyond Cabot straits.

The length of the Laurentian river, as mapped by Spencer, was 1,740 miles.

[1]Evolution of the Falls of Niagara, p. 394.

Since four of the present Great Lakes have depths reaching below sea-level, and three of them are included in the supposed ancient river channel, one must suppose that an important amount of differential warping of the earth's crust has occurred since these basins and their drift-filled connections supplied a continuous grade from the interior highlands to the sea. There are difficulties in accounting for these anomalies, but no better theory has thus far been suggested.



3. Map of the Laurentian River

Tributaries of the Laurentian River

If we assume that the Laurentian river existed, and that it threaded several now distinct basins, it is evident that there must have been numerous tributaries joining it. Spencer has indicated several of them on his map, the first being the Huronian river, formed of two branches, one coming from the depression of Saginaw bay, and the other running north from the southern portion of Lake Huron. In the Ontario basin he maps two tributaries, the small

Dundas river and the large and important Erigan river draining the Erie basin and a considerable area to the south. This he indicates as entering the Ontario basin by a buried channel crossing the Niagara escarpment just west of DeCew falls, three or four miles south of St. Catharines. A number of wells show that this valley was deep enough, or almost deep enough, to drain the Erie basin completely.[1] Grabau completely reverses this conclusion, however, and believes that a great river, roughly corresponding to the upper part of Spencer's Laurentian river, flowed southwest through the Dundas valley and the basin of Lake Erie. At the time he wrote the DeCew channel was unknown, or he would perhaps have chosen it as the course of the main drainage system.[2] Spencer's map shows three tributaries of the Erigan river coming in from Ohio and even from Pennsylvania to the south, one of them including the upper part of the Ohio river reversed in direction; so that the two writers seem entirely at cross purposes.

If we admit that Spencer's river system is not improbable, there are still some parts of the basins of the Great Lakes left unprovided for. Lake Superior is not included in his map; but Leverett reports a "buried channel leading southward from the east end of the basin to the head of Lake Huron some distance west of the present line of discharge through St. Mary's river;"[3] which may indicate a connection with the Laurentian river. On the other hand, it has been suggested that Lake Superior drained toward the southwest; and buried southward-pointing outlets have been reported near Chicago and near Cleveland, indicating the drainage of the Michigan and Erie basins into the Mississippi. At present the evidence does not seem decisive as to the direction of drainage of the westward and southward parts of the basins.

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[1]*Ibid.*, pp. 418-428.

[2]Bull., N.Y. State Mus., No. 45, Vol 9, p. 42-5.

[3]Outline, Hist. of Great Lakes, 12th Rep., Mich. Acad. Sc., 1910, p. 21.

Origin of the Lake Basins

All of the basins of the Great Lakes except that of Lake Erie reach below sea level. Lake Superior, with its average surface 602 feet above the sea, has soundings of 1,008 feet; Lake Huron, 578 feet above sea, has a depth of 700 feet; and Lake Michigan of 870 feet; while Lake Ontario, with a water level 246 feet above the sea, has a depth of 738 feet. Lake Erie, 571 feet above the sea, reaches a depth of only 204 feet. It is evident that there must have been great changes in the relative levels of different portions of the region to account for the great depths of the lakes just mentioned.

The dip of the Keeweenawan rocks surrounding Lake Superior is always lakewards, as if the basin had been formed by a downward bending of the sedimentary strata and the beds of lava found so extensively on its shores and islands. The shape of the lake suggests a syncline with a sharp northward bend in the middle. Some believe that the synclinal shape has been produced by lateral thrusts of a mountain-building character; but it is more probably the result of the removal from a central hearth of the vast quantities of lava piled up on its shores, thus allowing the surface beds to collapse. The much shallower basin of Lake Nipigon, which may be considered the first of the chain of lakes, seems to have been formed in the same way. It is improbable, however, that the basin of Superior could have remained unfilled during the enormous time since the latest Precambrian, so that here too one must suppose that it was for long a river valley draining west or south by a drift-filled outlet still undiscovered.

Lake Huron and Georgian bay occupy basins partly due to warping of the earth's crust, but largely caused by an immense dam of Pleistocene drift materials, glacial and interglacial, piled up to a height of 942 or even 1,200 feet above sea level, thus turning the drainage which once followed the Preglacial Laurentian river into the St. Clair, Detroit, and Niagara rivers.

The Lake Michigan valley probably drained partly into the Mississippi under Preglacial conditions; but the southward outlet is now blocked by drift of much less thickness than that between Georgian bay and Lake Ontario.

Lake Erie owes its shallow basin partly to the filling with drift of an old outlet toward Lake Ontario, but largely to differential uplift of its northeastern end.

Lake Ontario, also, probably has a drift-filled outlet toward the east, but has been greatly deepened by differential raising of the outlet at the Thousand Islands. The two lower lakes illustrate more distinctly than the others the formation of basins from river valleys by the elevation of the outlets. They have been formed mainly by the action of epeirogenic forces, and damming has been of minor importance, while Lakes Huron and Michigan are held up by dams of drift materials.

Precursors of the Great Glacial Lakes

The glacial lakes of Ontario and the adjoining states, as generally defined, include only those bodies of water formed during the retreat of the last, or Wisconsin, ice sheet, but it is evident that each of the earlier sheets which has covered the region must have dammed back the northward or northeastward flowing waters in a similar way, and, in fact, that each ice advance must have formed lakes which gradually diminished in area as the ice front moved southwards until the whole of their basins was occupied; and afterwards a series of lakes expanding as the ice sheet retreated when the climate became temperate again.

How often the Great Lakes region was invaded by ice is not entirely certain, though the geologists who have studied the drift of Iowa distinguish five successive ice sheets as having covered parts of that state; while each of four interglacial intervals indicates a great retreat of the ice, if not its complete removal, before the following sheet advanced. In Ontario there is positive evidence of one interglacial period of milder climate than the present, when

no ice sheet could have survived, and of another great retreat of the ice when the Ontario basin at least was set free. These earlier glacial lakes, whether formed by an advancing or a retreating ice sheet, have left only very fragmentary evidence of their existence, and any attempt to map their boundaries is out of the question, though there can be no doubt of their existence. Later ice advances have in most cases completely buried or removed the proofs of such bodies of water.

During the Toronto interglacial period there was a lake in the Ontario basin which stood at first 60 feet above the present lake, and later rose to about 150 feet. An interglacial successor of the Laurentian river drained the Huronian valley into the lake just mentioned, forming a great delta at Toronto covering more than 100 square miles with sediments having a thickness at Scarborough Heights of 190 feet. As the climate for part of this interglacial period was distinctly warmer than that of Toronto at present, as is shown by the trees of the time, ice cannot have served as a dam, and one must suppose that the waters were held up by a differential elevation of the outlet near the present Thousand Islands. Later the barrier was removed and the water fell to 40 feet below the present lake, as is shown by old valleys carved to that depth and then buried under the next boulder clay. This level may correspond to the supposed drift-filled outlet southeast of the Thousand Islands. The lake of the Toronto Formation had a rich fauna, including 41 species of shellfish, of which ten or eleven are unios, mostly forms now living in the Mississippi.[1] Fish remains occur also, the only certain species being a large catfish, as determined by Professor Bensley from a spine. The evidence as to climate furnished by the aquatic life corroborates the conclusions drawn from the trees, suggesting temperatures corresponding to points 4 or 5 degrees farther south at the present time. No interlobate moraine had been deposited across the Preglacial channel before the Toronto Formation,

[1]Guide book, No. 6, Geol. Congr. Tor., pp. 17-18.

so that the St. Clair, Detroit, Niagara outlet had not yet come into existence.

During the advance of the ice sheet which followed the Toronto interglacial time, a lake must have been formed in the Ontario basin, but no certain deposits belonging to it have been found. During the retreat of this ice sheet, which extended beyond Newcastle, fifty miles to the east, the glacial lake reached a level of 204 feet; and later the process was repeated twice more, as shown by beds of stratified sand and clay 25 and 36 feet thick respectively, between sheets of boulder clay, implying water levels 238 and 306 feet above Lake Ontario. A few small shells have been obtained from the second interglacial beds, belonging to species still living in the region; but the two upper sands seem to have been deposited in lifeless waters, probably with the ice front not many miles to the northeast. What took place in the basins of the other Great Lakes can in most cases only be inferred from our general knowledge of the advance and retreat of the great ice sheets which passed over the region; since lake deposits belonging to the successive interglacial intervals have not been certainly identified.

Lake Agassiz

The earliest of the glacial lakes, as usually defined, lay to the west of the region here specially considered and will be mentioned only briefly. Lake Agassiz, as it has been called, occupied parts of Saskatchewan, Manitoba, and Ontario in Canada, and parts of Minnesota and North Dakota in the United States. When at its greatest dimensions it covered 110,000 square miles between the watershed to the south and the retreating Keewatin and Labrador ice sheets, its northern shore being the margin of the Keewatin sheet and its eastern that of the Labrador sheet. It was a comparatively shallow lake which drained southeastwards by what has been called the Warren river into Minnesota river, a tributary of the Mississippi. When the two confluent ice sheets melted so far as to separate, a

channel was opened toward the northeast, Nelson river came into being, and Lake Agassiz was drained, leaving as its successors Lake Winnipeg and other bodies of water in Manitoba, and Lake of the Woods, etc., in Ontario.

In spite of its shores of ice to the north and east the temperature of the water and the general climate were not excessively cold, as is shown by the fauna. Warren Upham mentions *Unio* (=*Lampsilis*) *ellipsis*, *U.* (=*Obovaria*) *luteolus*, *Sphaerium Striatinum*, *S. sulcatum* and *Gyraulus parvus* as shellfish living in it.[1] Lawson states that bones of buffalo and shells of *Sphaerium sulcatum*, *S. Striatinum*, *Planorbis bicarinatus* (=*antrosus*) and *Lymnaea desidiosa?* occur in fresh-water beds in the Rainy River district.[2]

The present writer has found in stratified Agassiz clay at Fort Francis[3] *Lampsilis recta*, *Amnicola limosa*, *Lymnaea desidiosa*, *L. stagnalis?*, *L. palustris*, *Pleurocera sp.?*, *Planorbis bicarinatus* (=*antrosus*), *P. deflectus*, *Valvata sincera*, *V. tricarinata*, *V. bicarinata?*, *Sphaerium sp.? Pisidium* perhaps two or three species.[4] In addition, bones of a small fish and a bony plate of a sturgeon were obtained. Johnston reports shells at five different localities in sand and gravel beaches of Lake Agassiz and at numerous points in the lacustrine and fluvio-lacustrine deposits, but does not mention the species.[5]

In a shallow lake of such dimensions as Lake Agassiz the southern waters would naturally be considerably warmed in summer in spite of a northern shore of ice, and as a result its inhabitants, so far as is known, were all species still existing in Lake Winnipeg, the habitat of some of them extending far to the south. The outlet river would give easy access for species which had survived the Ice Age in the Mississippi waters beyond the limit of glaciation, so that the peopling of this newly formed sheet of water is

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[1]Glacial Lake Agassiz, Mon. XXV, U.S. Geol. Sur., pp. 237-8.

[2]G.S.C., Vol. III, 1887-8, p. 172 F.

[3]Bur. Mines, Ont., Vol. XI, 1902, p. 147.

[4]Mostly determined by Prof. A. D. Robertson.

[5]G.S.C., Mem. 82, pp. 54-5.

readily accounted for. The climate of Manitoba at the time was probably not much more rigorous than now, since the buffalo lived on the shores of the lake; and the fish and molluscs could not have multiplied as they did unless its waters were unfrozen for several months in the year.

Early Glacial Lakes in the Basins of the St. Lawrence System

Probably before Lake Agassiz was drained, the basins of the upper lakes of the St. Lawrence system began to be set free by the melting of the southern end of the ice lobes that occupied them. The evidences of this are found mostly in the states to the south of the province of Ontario, so that it will not be necessary to describe in detail these early glacial lakes. They have been mapped by Leverett, Taylor, Goldthwait, and others in the United States, and to a minor extent by Spencer in southern Ontario. A full and excellent account of them is given by Taylor in Monograph LIII of the United States Geological Survey, to which those specially interested in the matter are referred.

Numerous early stages of water have been recognized and more or less completely mapped in each of the three upper lake basins, but only the most long lived of them need be mentioned here. In the Superior basin Lake Duluth followed up the shrinking ice lobe and ultimately occupied about half of the present basin as well as flooding a strip of the present shores. It drained southwestward through the St. Croix river valley into the Mississippi.[1] This lake, when at its greatest extent, covered part of the Thunder Bay region in Ontario.

The southern half of Lake Michigan was occupied at first by a crescent-shaped lake which expanded northwards, and has been called Lake Chicago. It emptied toward the southwest by the valley of Desplaines river, a tributary of the Mississippi.

The southern end of Lake Huron and the basin of Lake Erie had a very complicated history and numerous names

[1]U.S. Mon. LIII, p. 328, map op. p. 400.

have been given to bodies of water following up the ice. Only one of these, Lake Warren, will be mentioned. Its beaches extend into the province of Ontario and were studied first by Spencer.[1] He supposed that the region was covered by an arm of the sea and named this extension of the Gulf of St. Lawrence the "Warren Water." Later it was recognized that it was a glacial lake having an outlet through what is now Saginaw bay into Lake Chicago. Spencer believed that this body of water extended far to the north and included the upper beaches around Lake Superior. He was followed in this by Lawson, who measured many beaches north of Lake Superior; and by the present writer in the same region and farther east. The more recent and more detailed work of Taylor and others in the United States has cut down greatly the dimensions of this lake, and the high beaches to the north are now known to belong to Lake Algonquin.[2]

At a later stage the waters of the Huron-Erie basin sank below the level of the outlet to Lake Chicago, and Lake Lundy took the place of Lake Warren. Some of its beaches are found in southern Ontario. It is supposed that Lake Lundy emptied toward the east through the state of New York and the Hudson valley.[3]

Lake Algonquin—Its Outlets

The various lobes of the Labrador ice sheet were gradually shrinking, though with some halts and even re-advances, marked by the building of moraines, and at length the basins of the Upper Lakes were almost completely free, though to the north and northeast, beyond the present boundaries of Lakes Superior and Huron, ice still formed a part of the shore. At first all outlets toward the northeast were blocked, but the basins of the three great Upper Lakes were in communication, forming what was called by Spencer Lake

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[1]Falls of Niagara, G.S.C., p. 287.
[2]U.S. Mon. LIII, pp. 392, 398.
[3]*Ibid.*, pp. 399-406.

Algonquin, and probably drained for a short time past Chicago into the Mississippi. Lake Erie was no longer dammed by the ice front and became partly a river valley, and partly a separate lake, through which for a time Lake Algonquin emptied into the Ontario basin. It may be that both of these channels functioned for a short time until the ice so far withdrew from the Georgian bay region as to allow a lower outlet past Kirkfield into the Trent valley.

Affairs were in a very unstable condition with regard to outlets, and also as to the area and shape of Lake Algonquin. When the Kirkfield outlet was opened, the land in that region stood lower than either the Chicago or St. Clair channels, and the great lake must have been lowered to correspond, leaving the earlier channels dry. As the load of ice was removed by thawing toward the northeast, the land beneath the thinning ice sheet rose to correspond to the relief, and at length the Kirkfield or Trent outlet reached a level when the St. Clair channel and perhaps also the Chicago channel were occupied once more. There was a long continued two-outlet or three-outlet stage during which a substantial beach was built round the whole shore. Ultimately, the northeastward elevation closed the Kirkfield outlet, and the reinforced St. Clair river lowered its bed in drift deposits so far that the Chicago outlet, limited by a sill of rock, ran dry, and the whole drainage of Lake Algonquin passed through the Erie valley and over Niagara Falls.[1]

During the two- or three-outlet stage of Lake Algonquin, there seems to have been a long halt in the retreat of the ice and also in the elevation of the region toward the north. In the southern parts of the basins, although the shore stood higher than at present, the area occupied followed pretty closely the boundaries of the present lakes. Toward the north, northeast and east, however, Lake Algonquin extended much beyond the present limits, a northern bay even including the basin of Lake Nipigon. Much of the land north of the Sault Ste. Marie and northeast of Georgian

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[1]*Ibid.*, pp. 407, etc.

4. Map of Lake Algonquin

bay was flooded; so that the lake covered considerably more space than the three Upper Lakes. It had an area of perhaps 100,000 square miles, coming next to Lake Agassiz in dimensions and far surpassing it in volume of water, since parts of its basin had a depth of from 1,200 to 1,500 feet.

The southwestern shores of Lake Algonquin have been carefully mapped, but the northern and northeastern are still only imperfectly known, since the region is largely forest-covered and roadless.

Present Altitude of the Shore of Lake Algonquin

A detailed account of the southern shores of Lake Algonquin, accompanied by an excellent map, is to be found in Taylor's description of the Post-glacial lakes.[1] It has been determined that along the southern half of Lake Michigan and the lower ends of Saginaw bay and Lake Huron the old shore is horizontal and rises 607 feet above the sea or 26 feet above the present lakes. The horizontal portion ends at what is called a "hinge line" crossing the lakes in a direction about 20° south of east and entering the province of Ontario at the village of Grand Bend, northwest of London. Beyond the hinge the shore rises as one goes north. At Kirkfield, for a long time on the main outlet of the lake, the shore is 883 feet above the sea, showing a deformation in the distance of 276 feet, about two feet per mile in the direction of tilt. The highest beach rises more rapidly farther north, reaching 1,007 feet at Huntsville, as determined by Goldthwait, and 1,015 feet at Root river, six miles north of the Sault Ste. Marie, according to Leverett.[2] Up to these points the position and elevation of the highest shore is considered to be somewhat definitely fixed. A number of shore deposits probably belonging to it are known still farther north, however. At Heyden station on the Algoma Central Railway, 13.3 miles north of the Sault, there is a gravel plain 1,082 feet above the sea, which almost

[1] *Ibid.*, pp. 409-438.
[2] *Ibid.*, p. 435.

certainly belongs to Lake Algonquin; and Goldthwait has found a probable Algonquin beach at Trout Creek, 54 miles north of Huntsville and 1,221 feet above the sea, representing a rise of about four feet per mile between the two places. Northward of the hinge line the beach is split up into groups of successive beaches, showing that elevation was progressing during the lifetime of the lake.

The northeast shore of Lake Algonquin has never been traced continuously, though at many localities lake deposits or old beaches have been found which probably represent Algonquin water levels, a few of them belonging to the highest beach, but most of them corresponding to lower stages of the lake, after the Kirkfield or Trent outlet had been abandoned and the drainage followed the St. Clair river toward Niagara Falls. A number of these points are along railways, since the location engineer is much attracted by flat plains or level beaches; and many of the divisional stations, where yard facilities are required, have been located on lake deposits. In these cases the levels are definitely known. In other cases the old lake deposits have been measured by aneroid during canoe trips or walks across country, and the elevations are much less certain. As it will probably be many years before the wild region north of the lakes is carefully surveyed, it is thought advisable to give these aneroid determinations in spite of their possible want of accuracy. It is not thought necessary, however, to give aneroid levels of old beaches near points where Wye level surveys have been made by Lawson and others, though many such determinations were made.

Water Levels in the Sudbury and Sault Districts

Lake deposits are widespread in the Sudbury District, about 90 miles a little north of west from North Bay and 150 miles northwest of Kirkfield. The deposits include plains of stratified clay, mostly in the interior of the nickel basin, running from 820 feet at Coniston to 889 at Chelmsford (both railway levels), indicating moderately deep water

conditions in a bay of Lake Algonquin. To the north sand plains occur at Hanmer (968) and Capreol (1,003) stations, and there is a gravel terrace five feet above the track at Selwood Junction (1,089). Along the main line of the Canadian Pacific Railway northwest from the Sudbury basin there are sand plains, succeeded by gravel plains at Windy Lake (1,221) and at Cartier (1,378). The last is a divisional station with many switches and tracks laid out on a gravel flat, which probably belongs to the highest Algonquin beach. All these figures are from railway levels, and are accurate. The highest sand and gravel plain observed in the district is at Meteor lake about 50 miles north of Chelmsford and 45 miles in a direction about 20° east of north from Cartier. Aneroid readings make the level 1,420 feet, which would give a rise of one foot per mile from Cartier, probably under the true rate of change. The Meteor lake region is a pitted plain enclosing steep-walled kettles which were formed by the slow thawing of ice masses buried under lake shore deposits, at the margin of the retreating ice sheet.

Although no continuous shore has been traced in the Sudbury District the widespread character of the lake deposits and their position rising gradually to the north of Lake Huron, make it certain that Lake Algonquin when at or near its highest level extended at least 50 miles and probably 90 miles from the present coast of Lake Huron.

On a former page reference was made to high level sand and gravel terraces along the Algoma Central Railway, extending for thirteen miles north of the Sault Ste. Marie. Many old lake beds have been found farther to the north, partly along the shore of Lake Superior on the route to Michipicoten, and partly inland beyond Michipicoten bay.

The first point measured (by aneroid) is on the northeast side of Batchewana bay, thirty miles north of the Sault, where three terraces stand at 967, 1,047, and 1,152 feet respectively. The highest terrace is 70 feet above the highest one near the Sault, giving a rise of two and a half feet per mile.

The next measurements were made near Brulé harbour,

92 miles in a direction a little west of north from the Sault. Here, on a path from Brulé harbour to the mouth of Old Woman bay a wonderful succession of bars is found having the following elevations:

867 feet	Algonquin beaches
858 "	
842 "	
823 "	
814 "	
750 "	
734 "	
724 "	
706 "	
658 feet	Nipissing beaches.
636 "	
623 "	
612 "	

The elevations up to 734 feet were determined by hand-level, the higher ones by aneroid. The beaches are practically continuous from 814 to 823, and from 842 to 867 feet. In fact there are only two wide gaps in the succession, one above what are considered Nipissing levels and one between 750 feet and 814. The levels given were measured from Brulé harbour up to a col between granite hills at 867 feet, but a similar succession goes down to Old Woman bay on the other side. They are all gravel or boulder beaches, and are very recent-looking up to 56 feet above Lake Superior, being free from trees or bushes, though covered with lichen.

Twelve miles northeast of Brulé a branch of the Algoma Central railway runs from Michipicoten harbour to the Helen mine, its route being mainly over great delta plains of sand and gravel deposited by Michipicoten river in Lake Algonquin and later bodies of water. Somewhat east of the harbour, on a road leading from the Mission to Wawa lake, ten terraces or beach ridges were hand-levelled, run-

ning from 623 to 810 feet. One at 681 feet is a broad sand terrace, perhaps the highest Nipissing beach, though the greatest break, of thirty feet, is just above 702 feet.

Brient Station on the railway is on a terrace of stratified sand at 759 feet and Wawa Station, on a gravel terrace, is at 960 feet, while Wawa lake is at 938 feet. The lake is dammed by a bar at the railway level (960 feet), and was a bay of Lake Algonquin cut off by wave action.

Higher beaches reach 1,042, 1,088, and 1,140 feet, as determined by aneroid. At Goudreau lake, twenty-eight miles northeast of Michipicoten harbour, a distinct bar was hand-levelled from a bench mark on a railway "try line," working out at 1,330 feet above sea level.[1]

Thirty miles northwest of the harbour a beach was found at 1,382 feet on Obatonga lake, and about ten miles farther northwest, on Pokay lake, there is a beach at 1,445 feet (both aneroid levels). This is the highest water level observed in the region, but at several C.P.R. railway stations east of Michipicoten there are lake deposits at about the same level. Pardee, 60 miles east, is on a sand plain (1,524 feet), and Chapleau, a divisional point 70 miles east, is on a sand plain (1,412), with a higher terrace including glacial kettles between it and Poulin station (1,499). Eighty miles east, at Nemegos (1,421), there is a sand plain, and near Winnebago, 100 miles east, there is a gravel plain and railway ballast pit at 1,447 feet.

Winnebago is 80 miles northwest of Cartier and north of the Sault; and it is evident that, as usual, the railway has chosen for its route the sand and gravel plains and terraces of the old shore. The position of the railway roughly outlines this part of Lake Algonquin at its highest stage.

Algonquin Beaches Northeast of Michipicoten Bay

The shore of Lake Superior between Michipicoten harbour and Heron bay, where the C.P.R. reaches it, is comparatively

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[1]This beach was first put at 1,430 feet, but later it was found that the bench-marks were adjusted to 100 feet below the level of Lake Superior so as to allow for under-water work at the harbour.

little known, since it is not touched by any travelled route and can be studied only by using fishing boats. At the mouth of Dog river, fifteen miles west of Michipicoten harbour, beaches have been measured by aneroid at 721, 851 and 962 feet; probably all belonging to Lake Algonquin. Farther to the west the shore is mountainous and too rocky and precipitous to provide much beach material, and the same is true of the shore bending northwest toward Heron bay. At Kilkenny, a small fishing harbour just at the bend, excellent gravel beaches were hand-levelled at 610, 618, and 644 feet, the highest one probably belonging to the Nipissing beaches. As the highest mountains in Ontario rise within a few miles of the shore (Tip-top, 2,120 feet, is the culminating point), it is evident that there must have been a large promontory or island here in Algonquin times.

The railway levels on the C.P.R. between Pardee and Heron bay are mostly below 1,200 feet, though some "summits" reach nearly 1,500 feet; but no well defined water levels have been observed, except possibly the flat on which White river (1,225 feet), a divisional point, is located. It is possible that the ice front remained for a long time in contact with the mass of high land between Michipicoten and Heron bays. The region deserves a much more careful study than has yet been devoted to it.

Michipicoten island, forty miles southwest of Michipicoten harbour, displays, as might be expected, a fine series of beaches, which fall into distinct sets; the lowest from 617 to 624, the next from 667 running to 680, and a third from 730 to 780 feet. At 806 feet there is a well-marked gravel beach and a lake dammed by beach materials. There is a wide terrace at 835 feet including a lake, and a highest terrace at 897 feet.[1] The beaches above 680 feet may be reckoned as belonging to the Algonquin series, which, however, is not complete, the highest members being lacking. The measurements were by aneroid.

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[1]Bur. Mines, Vol. 8, 1899, pp. 154-5.

Where the shore of Lake Superior turns from northwest to due west, at Peninsula, the following beach levels have been measured by aneroid:

980 feet	687 feet
959 "	669 "
732 "	647 "

Of these the levels above 687 come within the Algonquin limits. Forty miles east of Peninsula a sand plain at Bremner station (1,132) probably represents an Algonquin water level. This point is twenty-two miles northwest of Pokay lake, previously mentioned as showing one of the highest beaches recorded.

To the northeast of Peninsula, Pic river has piled up widespread delta materials, and sand terraces rise to levels of 757, 820, and 895 feet, representing low stages of Lake Algonquin. West of Peninsula, terraces were measured at several places, but Lawson's work, done with a Wye level, is more accurate, and only terraces above his determinations will be given.

At Jackfish bay Lawson records beaches running from 721 to 1,020 feet; and at the well named station, Terrace, there are terraces at 830, 845, 920, 974, and 994 feet. At Schreiber, a divisional station, Lawson gives a lake level at 993 feet, and one and a half miles west I have found one at 1,037 feet (aneroid). At Winstons, eight miles west, he mentions only one beach level, at 812 feet, but my aneroid readings show terraces of Lake Algonquin at 832, 890, 931, 967, and 985 feet also. Where the C.P.R. crosses Nipigon river Lawson gives seven terraces, of which only the highest, at 734 feet, can be considered to belong to Lake Algonquin.[1]

Beaches in the Nipigon Region

Besides the water levels at the mouth of Nipigon river a number of terraces occur farther north, showing that Lake Algonquin included most or all of the Nipigon basin. Twenty-four miles northwest, on Nonwatin lake, a sand

[1]Geol. and Nat. Hist. Survey of Minnesota, 20th An. Rep., 1891, Table, p. 280.

plain occurs at 917 feet (aneroid); and still further in that direction, on Black Sturgeon lake, there is a terrace at 660 feet (railway try line) and another at 963 feet (aneroid), the lowest one belonging to the Nipissing levels.

The Pleistocene features of the west side of Lake Nipigon have, so far as I am aware, not been studied; but on the east side there are broad sand plains at Poplar Lodge and for thirty miles to the east.

Lake Nipigon, the first of the chain of Great Lakes, is 852 feet above the sea or 250 feet above Lake Superior. By hand level and aneroid sand plains and terraces have been measured at 907, 930, 947, 987, and 1,020 feet within a few miles of the lake near Poplar Lodge. Farther east there are higher plains at 1,060 and 1,070 feet (aneroid) and at Kinghorne station on the Canadian Northern railway at 1,090 feet.

Poplar Lodge is 46 miles in a direction 5° east of north of the mouth of Nipigon river. Twenty miles farther north, near Red Paint river, there is a sand plain 922 feet above the sea, as determined by hand level from Lake Nipigon. A few miles to the northeast a moraine forms the watershed toward James bay (1,065 feet). Moraines cover much of the watershed north and northeast of Lake Nipigon and thus far no lake deposits have been recognized there.

It is probable that during most of the life of Lake Algonquin the shore in this region was of ice. As the highest Algonquin levels should reach above 1,500 feet in the northern part of the Nipigon area one may reasonably conclude that during the earliest stages of the lake most of the Nipigon basin was still ice-filled. In the later stages, with water levels of from 900 to 1,090 feet, the Nipigon bay of Lake Algonquin must have been about the size of Georgian bay, and with its numerous Archaean islands must have considerably resembled the latter.

Lake deposits are widespread to the southwest of Nipigon river and their elevations have been determined at a number of points on the C. P. Railway. Lawson records terraces in several places on or near Thunder bay, many of them

reaching the Algonquin level; the same is true along the coast of Minnesota to the southwest.

The old lake Kaministiquia described by Taylor from deposits west of Fort William was probably a part of the highest Algonquin waters, which attained from 1,400 to 1,500 feet above sea level.[1]

Whether this stage extended across the watershed between the Great Lakes and the waters draining into Lake Winnipeg is not certain. The elevations of the railway summits beyond Lake Superior are 1,568 feet for the Canadian Pacific near Martin station and 1,580 feet for the Canadian Northern at Huronian station. It is doubtful if the highest Algonquin waters ever connected with those of Lake Agassiz across this watershed. The greatest elevation of lake deposits observed by myself west of the watershed is at Ignace, forty miles beyond the summit (at Martin), where a gravel terrace used for railway ballast rises seven or eight feet above the track, which is 1,486 feet above the sea. The gravel terrace reaches about 15 feet above the track somewhat to the east of the station, *i.e.*, 1,501 feet, considerably below the watershed.

The highest Agassiz beach reported by Johnston in western Ontario is only 1,200 feet above sea level,[2] and it seems improbable that the two greatest glacial lakes ever mingled their waters. The only certain connection between them is through the rivers which drained them into the Mississippi. This connection is long and round-about and it is not probable that the two lakes drained into the great river contemporaneously.

Algonquin River

Although neither the earliest nor the latest effluent of Lake Algonquin, the Kirkfield or Trent channel is the most interesting of its outlets and probably functioned for a longer time than any of the others, though toward the end the

[1]Am. Geol., Vol. XVII, 1896, p. 254.

[2]G.S.C., Mem. 82, Rainy River Dist., p. 59.

waters of the lake were divided between the Algonquin and the St. Clair rivers and finally passed entirely into the latter. The most careful study of the outlet has been made by Johnston,[1] though it had previously been observed and described by Gilbert, Taylor and others.[2]

The route followed by the river was in the main that of the Trent Valley canal. A bay of Lake Algonquin, covering the present lakes Couchiching and Simcoe, extended eastward from Kirkfield to Fenelon Falls, where the Algonquin river began. It flowed through the basins of Sturgeon, Pigeon, Buckhorn and Stony lakes and then followed either the Otonabee or the Indian river valley to Rice Lake, at that time a bay of Lake Iroquois, which will be mentioned later. The old channel has been traced down the Trent valley to the Bay of Quinté and Lake Ontario, showing that Lake Algonquin survived Lake Iroquois for a period of time long enough to excavate a wide and deep channel to the present level of Lake Ontario if not below it. The present Trent river is far too small to have carved out the valley it occupies.

The puzzling feature of this continuation of the Algonquin river channel so far below the level of Lake Ontario lies in the fact that between the draining of Lake Iroquois and the formation of Lake Ontario there came the marine episode when the basin of Ontario was invaded by an arm of the sea, which stood in the Bay of Quinté region seventy-eight feet above the present Lake Ontario.

The solution of the problem is probably to be found in the fact that when Lake Iroquois ended the sea was much lower than now, since a part of the water of the globe remained stored in the great ice sheets still remaining on the continents. If we suppose that only half of the world's ice caps had melted when the glacial tongue which held up Lake Iroquois at the Thousand Islands disappeared, the sea was

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[1]G.S.C., Mus. Bull., No. 23, The Trent Valley Outlet of Lake Algonquin.
[2]U.S. Mon. LIII, pp. 410, etc.

80 or 100 feet lower than now, according to computations which will be mentioned later.

For most of its existence, according to Johnston, Algonquin river flowed through the Indian river channel, one of the present connections between Stony lake and Rice lake. He infers this from the magnitude of the delta built at its mouth in the Rice lake bay of Lake Iroquois.[1] Ultimately the northward elevation of the region turned the water into the Otonabee channel, when an important delta was made in old Lake Peterboro, a little above Rice lake.[2] The low marine stage probably occurred while the latter channel was in use, when the Algonquin river flowed down the Trent valley to the level of Lake Ontario.

Life and Climate of Lake Algonquin

At Tolleston near Chicago, in beds probably belonging to one of the earlier glacial lakes, many shellfish occur and also bones of several species of fish and of a duck, as well as leaves of oak (*Quercus marceyana*) and cones of spruce (*Picea evanstoni = canadensis?*). The middle Tolleston, which F. C. Baker considers to correspond to the Algonquin beach, also contains fifteen species of molluscs. Another stage includes eleven species of heavy unios characteristic of the Mississippi, among them five which occur in the Toronto interglacial beds on the Don. Except the spruce, which does not grow so far south as Chicago, all the species inhabit the same region now and indicate a climate like the present. One or two of the molluscs even suggest a climate warmer than the present.[3]

The Tolleston deposits were formed at or near the old outlet of Lakes Chicago and Algonquin in shallow water more than 400 miles south of the northern shore of ice, so the evidence is not conclusive as to temperatures in the lake as a whole.

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[1]G.S.C., Mus. Bull., No. 23, pp. 11, etc.

[2]Bull. Geol. Soc. Am., Vol. 15, 1904, pp. 357-8.

[3]Ill. Acad. Sc., Vol. IV, 1911, Post-glacial Life of Wilmette Bay, Glacial Lake Chicago.

In the Algonquin beach near Jackson point on the shore of Lake Simcoe, Johnston has found fresh water shells including *Lymnaea palustris*, *L. decollata* and *Sphaerium rhomboideum;*[1] all still living in Georgian Bay. He has found them also at Roche's point and Wilfred, and says: "The occurrence in the deposits of the highest shore-line of Lake Algonquin of fossil shells of mollusca similar to those living in Georgian Bay, and the fact that the fossil shells are only slightly reduced in size show that the temperature conditions of the water could not have been much more severe than at present. This is also borne out by the general absence of ice 'ramparts' on the abandoned shores of Lake Algonquin and the rare occurrence of boulders in the lacustrine deposits of the lake."

In my own work fossils have been found in Algonquin sands 810 feet (aneroid) above the sea on Pic river, 35 miles above the C.P.R. at Heron bay, including fragments of *Unio* or *Anodon*, *Sphaerium*, *Pisidium*, *Goniobasis*, *Lymnaea*, *Planorbis*, *Amnicola*, *Succinea*, *Valvata*, and probably two or three other genera. Unfortunately the species were not determined, but all the genera still live in Lake Superior.[2]

Many years ago Robert Bell reported shells from Pic river 30 feet above the water and the same distance below the top of the bank, but it is uncertain whether the deposits belong to Lake Algonquin or the Nipissing Great Lakes. They include two *Unios*, an *Anodon*, and a *Margaritana*, with species of *Lymnaea*, *Planorbis*, *Valvata*, and *Amnicola;* "the whole being of a more southern type than the mollusca at present inhabiting the rivers and lakes of the neighbourhood."[3]

Three miles above the Mission on Michipicoten river near its mouth there is a deposit of peat and logs six or eight feet above the water. An expert lumberman has recognized white pine, jack pine, white and black spruce, balsam, cedar,

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[1]G.S.C., Mus. Bull., No. 23, pp. 15 and 16.
[2]Bur. Mines, Ont., Vol. 18, 1909, p. 153.
[3]G.S.C. An. Rep., 1870-71, p. 328.

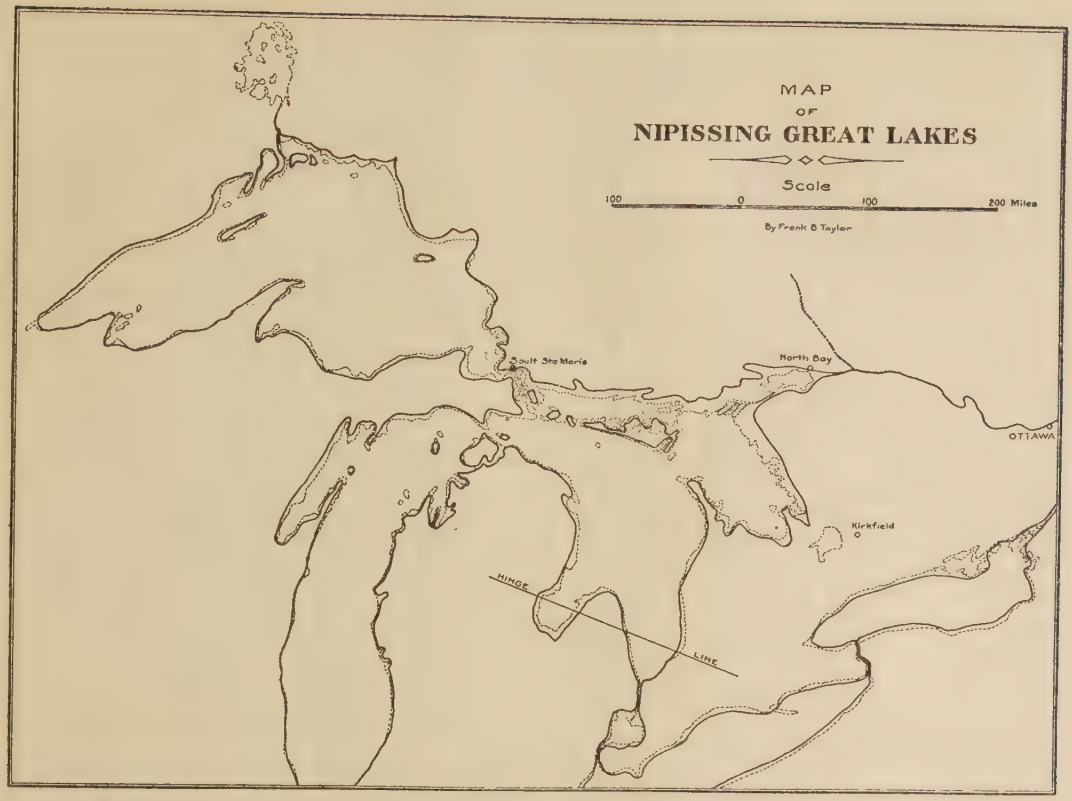
and poplar among the logs and fragments of wood; and in the peaty matter there are leaves of deciduous trees and of cedar and spruce, scales of pine cones, and some mosses. The age of the bed of clay in which they occur is uncertain, but it is older than the sand and gravel terraces which overlie it. These are beach deposits of the Nipissing Great Lakes. The peaty clay with wood was probably formed in moderately deep water at a low stage of Lake Algonquin.

It is notable that none of the shellfish or trees observed in Algonquin beds suggest a subarctic climate, such as might have been expected in connection with a lake whose shore was partly formed by the ice front. All the plants and animals still live in the waters or on the shores of Lakes Superior and Huron; so that there is no evidence that the climate was colder than at present. It may be that the slowly melting edge of the ice was largely buried under morainic materials on which trees could grow, as on the Malaspina piedmont glacier in Alaska.

At present the temperature of the water of Lake Superior is about that of greatest density, 39.2° Fahr.; and it is not unlikely that Lake Algonquin had the same temperature, while the shallow water of its southern temporary outlet near Chicago must have been much warmer to permit the life of so many Mississippi shellfish as have been found in the Tolleston beds.

The Nipissing Great Lakes

The final removal of the ice from the northeastern edge of the Algonquin basin opened a new outlet, at that time lower than the one by St. Clair river, through Lake Nipissing and the Mattawa valley to the Ottawa. The waters of the Upper Lakes were lowered to correspond and what has been called by Taylor the Nipissing Great Lakes resulted, the basins of Lakes Superior, Michigan and Huron being at the same level and communicating by straits so that St. Mary's river did not yet exist.



5. Map of Nipissing Great Lakes

The Nipissing Great Lakes lasted long and formed a pronounced beach which has been traced almost all the way round their shores. In area they were only slightly larger than the present lakes, though there was an extension toward the east covering the valley of French river and Lake Nipissing and ending at North Bay, where the outlet river began. A detailed and excellent account of these lakes and their shores has been given by Taylor,[1] and it is not necessary here to give more than an outline of their history.

Rise of the land toward the northeast gradually restored the use of the St. Clair channel and during most of their history the Nipissing Great Lakes had two outlets. Finally the rise toward the northeast turned all the water southwards, the North Bay channel went dry and the present lakes came into existence.

South of the "hinge line" mentioned on an earlier page the Nipissing beach is horizontal, ten or twelve feet lower than the Algonquin beach, and about 15 feet above the present Lakes Huron and Michigan. North of the hinge the Nipissing shore is split up into a series of beaches closely following one another.

At the North Bay outlet the highest Nipissing beach has been fixed at 698 feet by Goldthwait,[2] and to the south it becomes lower until at Sarnia near the hinge line it is only 597 feet. At Sault Ste. Marie it is 651 feet above sea level and on the north shore of Lake Superior it rises to its highest levels, given by Taylor as 703 feet at Jackfish bay and 710 (aneroid) at Peninsula harbour,[3] the point farthest from the hinge line and a little north of the isobase of North Bay. Probably the lower terraces along Pic river represent the highest known portion of the Nipissing shore. Delta materials are widely spread along the river valley; and one sand and gravel terrace twelve miles above the railway bridge and eight miles from Peninsula is at 718 feet (aneroid),

[1]U.S. Mon. LIII, pp. 447-462.
[2]*Ibid.*, p. 459.
[3]*Ibid.*, p. 460.

6. Nipissing Beaches at Brulé

and no doubt belongs to the Nipissing shore,[1] while others a few miles up the river, somewhat higher though not measured, probably represent a continuation of it.

A few other localities on the northeast shore of Lake Superior may be added to those mentioned by Taylor. The highest point after Pic river is probably at the Mission near the mouth of Michipicoten river, where terraces were measured by hand level, beginning at 623 feet above the sea (21 above Lake Superior) and continuing with comparatively small gaps up to 702. An interval of thirty feet separates this series from the next, which may be considered to belong to the Algonquin set of beaches. According to the isobases shown on Taylor's map, 702 feet is six or seven feet above the proper level. On the other hand, a broad sand terrace at 681 feet seems too low as compared with the isobases. Which should be taken as the highest Nipissing beach is uncertain, though the 702 feet level seems to the writer the more probable one.

Near Brulé harbour, ten miles south of Michipicoten, very well formed beaches were hand-levelled with only small gaps from the present lake level up to 658 feet, which may be considered the highest Nipissing terrace.

On Michipicoten island, just touched on the north by Taylor's isobase of 676, aneroid readings show a first series of beach ridges up to 22 feet, where there is a sea cave, a second series up to 65 feet, where a terrace affords space for several houses, and above this a succession of faint stages up to 78 feet, followed by a gap before the next water level at 128 feet. Probably the beaches at 667 and 680 feet belong to the Nipissing set and the higher ones to Lake Algonquin.

Life and Climate of the Nipissing Great Lakes

Shells have been found in Nipissing beach gravels at various places. Taylor mentions *Unio luteolus*, (=*Lampsilis luteola*), *Sphaerium Striatinum*, *Lymnaea elodes*, and *Gonio-*

[1]Bur. Mines, Ont., Vol. 18, 1909, p. 153.

basis depygis as occurring near Cheboygan, Mich.[1] These are common forms in the Great Lakes at present.

Many years ago Dr. Chapman, professor of Geology in the University of Toronto, described shells from deposits on the banks of Nottawasaga river near Georgian Bay. At Angus on the west bank of the river 30 or 40 feet above Lake Huron he collected *Unio* (=*Elliptio*) *complanatus*, *Cyclas similis* (=*Sphaerium sulcatum*), *C. dubia* (=*Pisidium virginicum*), *Amnicola porata*, *Valvata tricarinata*, *V. piscinalis*, *Planorbis trivolvus*, *P. campanulatus*, *P. bicarinatus* (=*antrosus*), *Lymnaea palustris*, and *Physa ancillaria*. This point is about 20 miles from Georgian Bay. About twelve miles from the mouth of the river Dr. Bigsby found two layers from four to six inches thick closely packed with unios. He adds *Melania* (=*Goniobasis*) and *Paludina* (=*Campeloma*) to the list just given.[2] Probably shells and wood found at Owen Sound belong to beach deposits of Nipissing waters also.[3]

To the species secured by these older geologists may be added the following shellfish obtained by the present writer from the banks of Nottawasaga river: *Sphaerium rhomboideum*, *S. sulcatum*, *Pisidium noraboracense; Valvata sincera*, *Amnicola limosa*, *Goniobasis livescens*, *Lymnaea desidiosa*, *Planorbis deflectus*, *P. parvus*, *Succinea avara*, *Polygyra monodon*, and *Helix* (=*Polygyra*) *tridentata*. The collection includes nineteen species, seven of them mentioned in former lists. All of the species referred to above are still inhabitants of Lake Huron and suggest a climate similar to that of the present.

A very interesting set of river deposits along the Niagara, from Queen Victoria Park and Goat Island to about the Whirlpool, is probably of the same age as the Nipissing Great Lakes at their latest stage when the drainage was partly through the St. Clair, Detroit, and Niagara channels.

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[1]U.S. Mon. LIII, p. 452.
[2]G.S.C., Geol. Can., 1863, p. 910.
[3]*Ibid.*, p. 912.

These are mentioned in the *Geology of Canada* (1863) as containing *Planorbis bicarinatus* (=*antrosus*), *Physa heterostropha*, *Lymnaea caperata*, *L. stagnalis*, *Melania* (=*Goniobasis*) *Niagarensis*, *M. conica*, *M. acuta*, *Paludina decisa* (=*Campeloma decisum*), *Amnicola limosa porata*, *Unio* (=*Elliptio*) *gibbosus*, *U.* (=*E.*) *complanatus*, *U.*(=*Obovaria*) *ellipsis*, *U. rectus* (=*Eurynia recta*), *Margaritana* (=*Alasmidonta*) *marginata*, *Cyclas similis* (=*Sphaerium sulcatum*) and a land snail *Helix* (=*Polygyra*) *albolabris?*[1]

Miss E. J. Letson, in 1901, published a list of 31 shells from Goat Island with a description and figure of each species. Of these 24 are in addition to the species given above. They include *Pleurocera subulare* (=*acuta*), *Goniobasis livescens*, *G. haldemani*, *Amnicola limosa*, *A. letsoni*, *Bythinella obtusa* (=*Amnicola emarginata*), *Pomatiopsis lapidaria*, *Valvata tricarinata*, *V. sincera*, *Campeloma decisum*, *Sphaerium striatinum*, *S. stamineum*, *Pisidium virginicum*, *P. compressum*, *P. abditum*, *P. ultramontanum*, *P. scutellatum*, *Alasmidonta calceola*, *Quadrula solida* (=*Pleurobema solidum*), *Q. coccinea* (=*P. coccineum*).[2]

The present writer collected fourteen species of shells in Queen Victoria Park, a number of years ago. Of these five species are not included in the foregoing lists—*Sphaerium solidulum*, *Unio luteolus* (=*Lampsilis luteola*), *U. clavus*, (=*Pleurobema clavum*), *U. occidens* (=*Lampsilis ventricosa*) and *Margaritana* (=*Alasmidonta*) *marginata*. In addition cyprids and chara may be mentioned as well as bones of mammoth found by Hall many years ago.

In all 36 species of shellfish have been obtained from the river sands and gravels near the Falls. Most of them still live in the river, but four of the species, *Lampsilis ventricosa*, *Pleurobema solidum*, *P. clavum* and *Alasmidonta marginata*, it is stated, are not found in the lakes but are Mississippi forms.[3] They must have reached Niagara river in a round-

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[1]G.S.C., 1863, pp. 913-14.

[2]Bull. N.Y. State Mus., No. 45, Vol. 9, 1901, pp. 238-252.

[3]Stockholm Geol. Congr., Changes of Climate since the last Glaciation, pp. 386-7.

about way going north from the Chicago outlet, when it was in operation, through Lake Michigan and then south through Lake Huron, St. Clair river, etc., to Niagara Falls.

Whether the Mississippi shellfish should be held to imply a milder climate than the present is uncertain. The three unios mentioned and four others occur in the Toronto interglacial beds associated with trees now growing in Pennsylvania and Ohio, suggesting a climate 4° or 5° warmer than the present.[1] Twenty-one out of the forty interglacial molluscs occur also in the lists from Niagara.

As the last remnant of the Labrador ice sheet had disappeared from Ontario south of the Hudson bay watershed it is very probable that the Nipissing climate was as warm as the present, and it may have been warmer, as suggested by the unios.

Lake Ojibway

The earliest and highest levels of Lake Algonquin reached 1,400 or 1,500 feet north and northeast of Lake Superior, as shown on previous pages; and it is known that there are at least three passes across the watershed toward Hudson bay which are very much lower than this. From west to east these are the passes at the head of Paint river, northeast of Lake Nipigon, at 1,046 feet (railway level); at Long Lake 22 miles from the north shore of Lake Superior, at 1,040 feet (aneroid); and at Missinaibi 45 miles northeast of Michipicoten bay, at 1,090 feet. It is evident that without some barrier Lake Algonquin at its highest stage would have extended indefinitely north of the watershed. This was prevented by the position of the ice front which stood at the divide or somewhat to the south of it, when Lake Algonquin began. Pitted plains in several places show the junction of ice and water.

As the ice retreated the land rose toward the northeast, but not rapidly enough to prevent Lake Algonquin, when

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[1]Geol. Congr. Mexico, 1906, Interglacial Periods in Canada, pp. 15, 16; also Geol. Congr., Toronto, 1913, Guidebook No. 6, pp. 15-18.

its waters stood at about 1,100 feet, from extending bays across the lowest portions of the watershed. These bays seem to have been of short duration, since no well-defined

7. Map of Lake Ojibway

shore forms extend northward from the Algonquin beaches at these points. This was demonstrated for the Missinaibi col by Taylor, who decided, from lack of beaches north of the divide, that the Algonquin water, as it had been named

by Spencer, was not a part of the sea but a separate ice-dammed lake.[1]

The northward rise of the land presently lowered the Algonquin shore to 1,000 feet or less and the northern bays were cut off from the parent lake. Probably they formed small lakes between the retreating front of the ice and the watershed, and ultimately merged into a large body of water which the present writer has named Lake Ojibway, from the Indian tribe occupying the region.[2]

The presence of a great body of fresh water in the position just suggested for Lake Ojibway is undoubted, since its deposits form the wide "clay belt" of northern Ontario, covering, according to explorations carried out for the Government of Ontario, an area of 25,000 square miles. The clay belt shows in many places beautifully stratified clay in annual layers from a half inch to an inch or two in thickness. The clay deposits have an undefined limit toward the north, but on the south pass into sandy shallow water materials and sometimes show beach gravels indicating the shore of the lake. Unfortunately, the region is still only imperfectly explored and is largely forest-covered, so that up to the present the exact boundaries of the lake have not been mapped, and it may be long before this work is undertaken. Toward the west the clay belt ends northeast of Lake Nipigon; and toward the east extends far into the province of Quebec. Whether the whole area of clay should be included in Lake Ojibway is doubtful. M. E. Wilson thinks that the Quebec clays were laid down in a separate body of water, which he names Lake Barlow.[3] He is probably correct in supposing that a lobe of ice occupying the depression of Lake Timiskaming separated the two bodies of water, at least for a part of their existence, and whether they united for a time when this ice lobe was melted remains uncertain. It is very desirable that some one should go over the ground more thoroughly than has yet been attempted, particularly

[1]Am. Geol., Vol. XVII, 1896, p. 255.

[2]Bur. Mines, Ont., Vol. 18, 1909, pp. 284-293.

[3]G.S.C., Mem. 103, 1918, pp. 140-145.

in the Timiskaming region, where a number of problems remain to be solved.

The point of outlet of Lake Ojibway is not certainly known. It was believed by the writer, when the name was given to the lake, that the outlet was by the valley of Lake Timiskaming into the Ottawa, but if this lowest part of the southern edge of the clay belt was filled with ice some other channel must be sought for. The waters may have escaped southward along the edge of the ice, in which case the channel would be a shifting one, moving from west to east; or the outlet may even have been over the ice, at least for a time, so that no direct evidence of it would be left.

Stratified clay is found on both sides of Lake Timiskaming toward its northern end, reaching levels of 642 to 776 feet near Haileybury, New Liskeard, and Uno Park, and of 648 to 796 feet at Baie des Pères on the Quebec side. Farther south near the mouth of Montreal river sand and clay terraces were measured from 624 to 811 feet. The measurements were made partly with a hand level but mainly with an aneroid.[1] The clay beds were laid down probably in moderately deep water, but they are south of the watershed, which is at 935 or 940 feet, and cannot be considered as belonging to Lake Ojibway, though they are just like the Ojibway clays. It seemed probable at first that they were deposited in an extension of the Nipissing Great Lakes, whose outlet is only about fifty miles south of Montreal river where it enters Lake Timiskaming; but the finding by Gilbert, Taylor, and others of a channel draining the Nipissing Great Lakes into the Ottawa river at Mattawa, only 488 feet above the sea, seems to make this impossible.[2]

Johnston, repeating a measurement made by De Geer, puts the highest marine beach at 690 feet, near Kingsmere, eight miles northwest of the city of Ottawa, and suggests that a narrow arm of the sea extended to the head of Lake

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[1]Bur. Mines, Ont., Vol. 9, 1900, pp. 177-8.
[2]U.S. Mon. LIII, p. 448.

Timiskaming; so that the clays were probably laid down in a northern fiord of the Champlain sea. There is no evidence that the water was salt, since marine shells have not been found in the Timiskaming region.

In accounting for the clay terraces above 690 feet it is necessary to recall the fact that the marine water level rises toward the north at the rate of three feet per mile.

The suggestion just mentioned does not solve all the problems of the relations between Lake Ojibway and the Nipissing Great Lakes, for the North Bay outlet of the latter lake is given by Taylor as 698 or 700 feet, and since it is 50 miles north of the Kingsmere parallel, differential elevation would carry the marine level 140 feet above it. Apparently the North Bay outlet must have been opened considerably later than the highest marine stage at Ottawa, when elevation of the land had proceeded to the extent of more than 140 feet; and we must assume that ice still occupied the Nipissing-Timiskaming region when the highest marine level occurred at Ottawa.

To return to Lake Ojibway, the retreat of the ice on the north of the watershed at length gave an escape for its waters toward Hudson bay, and the lake came to an end. It was probably the most variable and short lived of the glacial lakes of Ontario. When it ended Hudson bay reached much farther south than at present, at one point coming within 150 miles of Lake Superior, but there is no evidence that salt water encroached on the lake deposits.

Estimates have been made of the time covered by Lake Ojibway by determining the annual layers of clay in its deposits. Baker states that the clay reaches twenty-six feet in a railway cutting near Ground Hog river and that the layers are from a half inch to occasionally three inches in thickness;[1] while M. E. Wilson estimates the clay beds of Lake Barlow as averaging less than twenty-five feet thick, and gives the maximum number of beds counted as 250. He suggests that this represents the number of years

[1]Bur. Mines, Ont., Vol. 20, 1911, pp. 231-2.

during which a given point was covered by the lake.[1] W. A. Parks found a thickness of 40 or 50 feet on the shores of Night Hawk lake;[2] and the present writer estimated the thickness near Matheson at about 50 feet. Railway engineers report a still greater thickness found in bridge work near Cochrane. If the layers average an inch in thickness, fifty feet would mean 600 years as the minimum duration of the lake.

The fauna of Lake Ojibway must have been acquired from the bays of Lake Algonquin, which crossed the watershed toward the end of the history of the latter lake and the beginning of the former. Only one record is available as to its character. M. B. Baker reports *Amnicola porata*, *Lymnaea elodes*, *L. pallida*, *L. umbilicus*, *Planorbis bicarinata*, *Succinea obliqua*, *Valvata tricarinata*, and a land snail, *Helix striatella;* but does not mention the locality where they were found.[3]

In all probability the Abitibi lakes and other smaller sheets of water which have succeeded Lake Ojibway inherited their inhabitants from it and ultimately from Lake Algonquin.

The shellfish listed above do not indicate more severe conditions than the present. The northern shore of melting ice was perhaps largely covered with débris and seems to have had little effect in chilling the water of the lake, especially on its shallow southern side.

Waters of the Ontario Basin

Lake Warren, one of the earlier stages of water, occupied the southern part of the Huron basin, the whole of the Erie basin, and extended along the south side of the Ontario basin; though most of the actual area of Lake Ontario was still filled with ice. The outlet of Lake Warren is considered to have been across Michigan to Lake Chicago and ulti-

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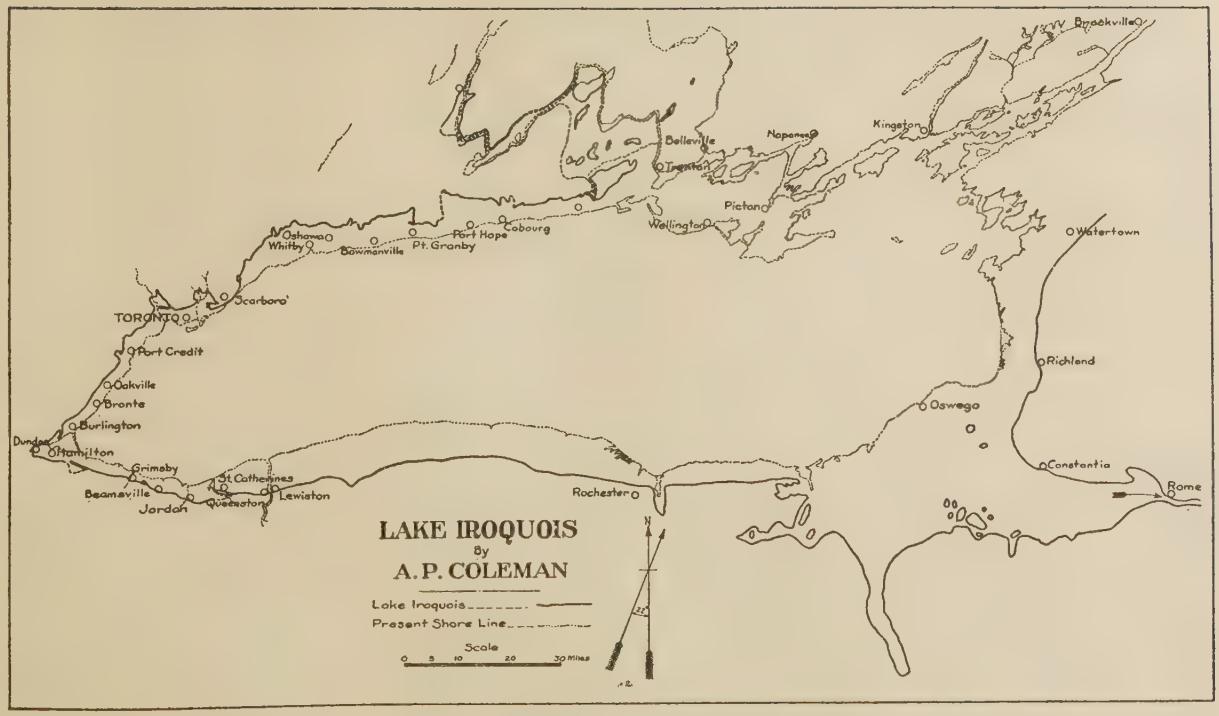
[1]G.S.C., Mem. 103, 1918, pp. 141-5.
[2]Bur. Mines, Vol. 8, 1899, p. 175.
[3]*Ibid.*, Vol. 20, 1911, p. 233.



8. Map of Lake Iroquois

9. Iroquois Shore, Scarborough

mately to the Mississippi. As the Ontario lobe of ice withdrew, lower outlets were opened toward the east, at what has been called the Lake Dana stage, and drainage through the Mohawk valley to the Hudson began. Finally the waters were lowered still further and Lake Iroquois came into existence. An elaborate series of beaches and outlets has been worked out in the state of New York, especially by Fairchild, and those interested in the matter will find reports and maps of the different stages in Bulletins of the State of New York.[1]

Lake Iroquois

Much the most long-lived and interesting of the bodies of water occupying a part or the whole of the Ontario basin is Lake Iroquois, first described by Gilbert in New York and by Spencer in Ontario, the appropriate name having been given by the latter writer. This was the first of the glacial lakes to be defined, and it has furnished the criteria by which the others have been studied. The abandoned shores of Lake Iroquois were the first on which the differential elevation of the beaches toward the north was demonstrated.[2] The shore of Lake Iroquois has been more completely and certainly worked out and mapped than that of most of the other glacial lakes, and the part within the province of Ontario has been studied in detail by the present writer.[3]

Lake Iroquois began as a narrow strip of water to the west and south of the ice lobe, but rapidly increased in area as melting proceeded until the whole Ontario basin was set free, when a considerably larger area was occupied than that of the present lake. The west half of Lake Iroquois follows closely the outline of Lake Ontario, but usually at a distance of from two to ten miles from the present shore.

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[1]Bull. 106, 1907, Glacial Waters in the Lake Erie Basin; and Bull. 127, Glacial Waters in Central New York.

[2]Falls of Niagara, G.S.C., pp. 277, etc.

[3]Bur. Mines, Ont., 13th An. Rep., 1904, pp. 225-244; also Bull. Geol. Soc. Am., Vol. 15, 1914, Iroquois Beach in Ontario, pp. 347-369.

At Scarborough Heights the Iroquois beach has been cut away for half a mile by the present lake. At Trenton in Ontario and at Sodus, New York, Lake Iroquois spread to the north and south far beyond the Ontario limits and reached a width of nearly 100 miles from the northwest to southeast. At the east end of the basin the northern shore is wanting for a distance of about 70 miles, where the ice barrier stood.

With the exceptions just stated, the Iroquois beach is as complete as that of Ontario, though cut through at various places by rivers. From Quay's Siding, about seven miles north of Port Hope, to Hamilton, and on the south side to Rome, N.Y., the beach is continuous, but to the northeast of these points it is split up into several strands which tend to spread apart toward the north. In reality the line from Quay's to Rome is a pivot about which the water level swung, rising in a direction N. 20° E. and sinking in the opposite direction. To the southwest of Quay's the earlier beach levels are buried more and more deeply under later beach deposits. This is shown at the reservoir park in Toronto, where beach materials go down 70 feet, and still better at the Desjardins canal cut near Hamilton, where undoubted beach deposits reach a depth of 83 feet.

It is evident that an important change of level was going on throughout the life of Lake Iroquois, the northeastern end rising either continuously or at frequent intervals. The differential elevation of the northeastern end of the beach as compared with the southwestern amounts in Ontario to 460 feet. At Hamilton, the lowest point of the latest stage of the beach, the present level is 362 feet above the sea, and at an old island near West Huntingdon, about twenty-seven miles north of Belleville, the beach is more than 744 feet above sea level.

Climate and Life of Lake Iroquois

The beaches of Lake Iroquois have proved fossiliferous near Hamilton and at Toronto. The splendid gravel bar extending north from Hamilton toward Burlington has supplied many animal remains including mammoth, wapiti,

10. Iroquois Gravel Bar, East Toronto

buffalo, and beaver.[1] Mammoth ivory and bones are frequently found in gravel pits and brickyards west of the bar also. Fragments of wood determined by Penhallow as *Larix americana* and *Picea* (probably *nigra*) have been found 30 feet below the surface in Hamilton, suggesting a cooler climate than the present.[2]

At Toronto many horns of caribou and a few bones of elephants including a mammoth tooth have been found in gravel bars; and also a number of shellfish—*Campeloma decisum*, *Pleurocera*, *Sphaerium*, and fragments of *Unios*, all still living in Lake Ontario. The mammals were animals that could endure a cold climate. At present the caribou ceases about 150 miles north of Toronto, and the mammoth had a heavy coat of hair. It is probable that the climate was somewhat colder than now, though not Arctic. As in the lakes previously described, the barrier of ice forming the shore toward the northeast did not prevent the waters from being inhabited. It may be that certain crumpled Iroquois sands near Toronto have been pushed by floe ice, but there is no evidence that icebergs floated on the lake, such as might be expected under glacial conditions.

Admiralty Lake

As the ice withdrew from Covey hill north of the Adirondacks, lower outlets than that of the Mohawk valley were opened, and Lake Iroquois came to an end.[3] The successive outlets were of relatively brief duration and only feeble records have been left in the way of beaches. One of the stages has been named Lake Frontenac, since it was held up by an ice barrier resting on the Frontenac axis of Precambrian rocks, but no definite shore line has been identified with it.[4]

Formerly it was supposed that as soon as the ice withdrew from the Thousand Islands the Ontario basin was

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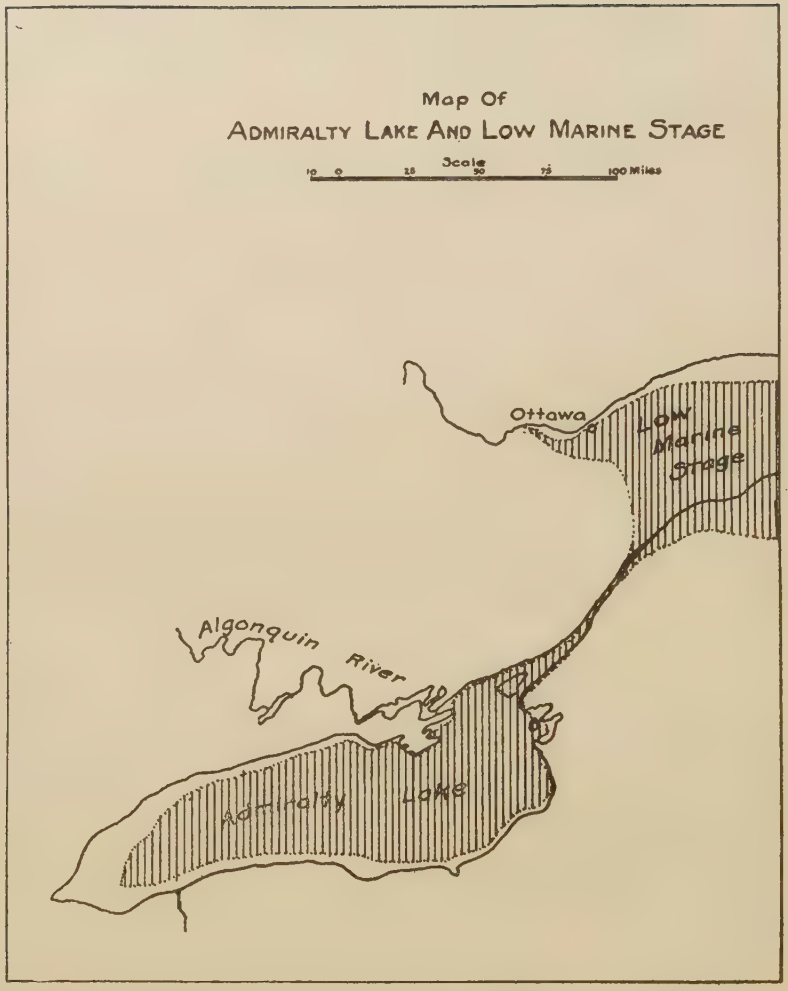
[1]Geol. Can., 1863, p. 914.
[2]Bull. Geol. Soc. Am., Vol. 15, 1904, p. 366.
[3]Fairchild, N.Y. State Mus. Bulls. 209 and 210.
[4]Taylor, U.S. Geol. Sur. Mon., LIII, p. 445.



11. Map of Admiralty Lake

flooded by the sea. The continuation of the Algonquin river channel down the Trent Valley, as mentioned on a former page, makes this view untenable. The base to which the valley was cut must have been somewhat below the level of Lake Ontario, and soundings in the Bay of Quinte suggest a possible delta near the mouth of the river, which may have been formed by Algonquin river or perhaps by the present Trent river. Some soundings lower down the Bay of Quinte reach 100 feet, perhaps in an ancient deep channel now partially filled; but there is no certainty that Algonquin river extended much below the present water level.

At that time the sea must have stood much lower than now, probably because a large amount of ice still remained unthawed upon the continents. It has been estimated by Drygalski[1] and Penck[2] that at the maximum of glaciation the amount of water withdrawn from the sea to form ice caps would lower it 150 metres. This is perhaps an over-estimate, and Daly's later determination of from 50 to 60 metres seems more probable.[3] To what extent the world's ice caps had shrunk when Lake Iroquois ceased to exist one can only guess. If we assume that only one half of the ice still remained, the ocean would still be 80 or 100 feet lower than now on Daly's assumption and 250 feet according to the German estimates.

The last beach in the Ontario region was probably formed much later, after most of the ice had melted, restoring nearly the full volume of water to the sea. At Trenton, where the Algonquin channel reaches the Bay of Quinté (level of Lake Ontario), there are several beaches, the best marked, at 78 feet above the present lake or 324 feet above the sea, probably representing the highest marine shore. If the sea was 80 or 100 feet lower when the channel was excavated, the basin must have been below the present

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[1]Zeit. Geo. Erdkunde, Berlin, Vol. 22, p. 274.
[2]Morphologie der Erdoberflaeche, p. 660.
[3]Proc. Am. Acad. Sc., Vol. 51, p. 173.

lake level and therefore must have contained an independent lake.

Two other factors which probably modified the conditions of the time should be referred to. The great mass of ice still remaining to the north must have exerted some attraction on the water, but probably would not raise its level more than fifteen feet according to an estimate by Woodward,[1] so that the depression of sea level might be counteracted to this extent. On the other hand, the outlet at the Thousand Islands was probably blocked by drift materials left by the ice sheet which had just vanished, presenting a barrier between the lake and the sea. At first this probably held up the water of the Ontario basin at least 25 feet, as shown by drift deposits at Gananoque; but later so easily attacked a barrier must have been removed by the strong river flowing east. The amount of tilting of the old water levels in the eastern part of the Ontario basin is two feet per mile, as will be shown later; and Trenton is 25 miles from the parallel of Kingston, where the outlet was, along the direction of tilt. The water level at Trenton must therefore have been 50 feet below the present when the twenty or thirty feet of drift filling the channels among the islands were removed, and this must have been quickly accomplished by a river as large as the St. Lawrence.

The body of fresh water occupying the Ontario basin when the Algonquin river reached the lowest point in its valley may be called the Admiralty lake from the beautiful Admiralty group of islands, between which its waters flowed seaward. Though its outlet must have been much the same as that of the present lake, the old shore of Admiralty lake is now below water, because of the northeastward uplift of the region, and its western end must have been about twenty-five miles east of Hamilton where the present lake has a depth of 220 feet. The St. Lawrence river was probably less than fifty miles long at this time.

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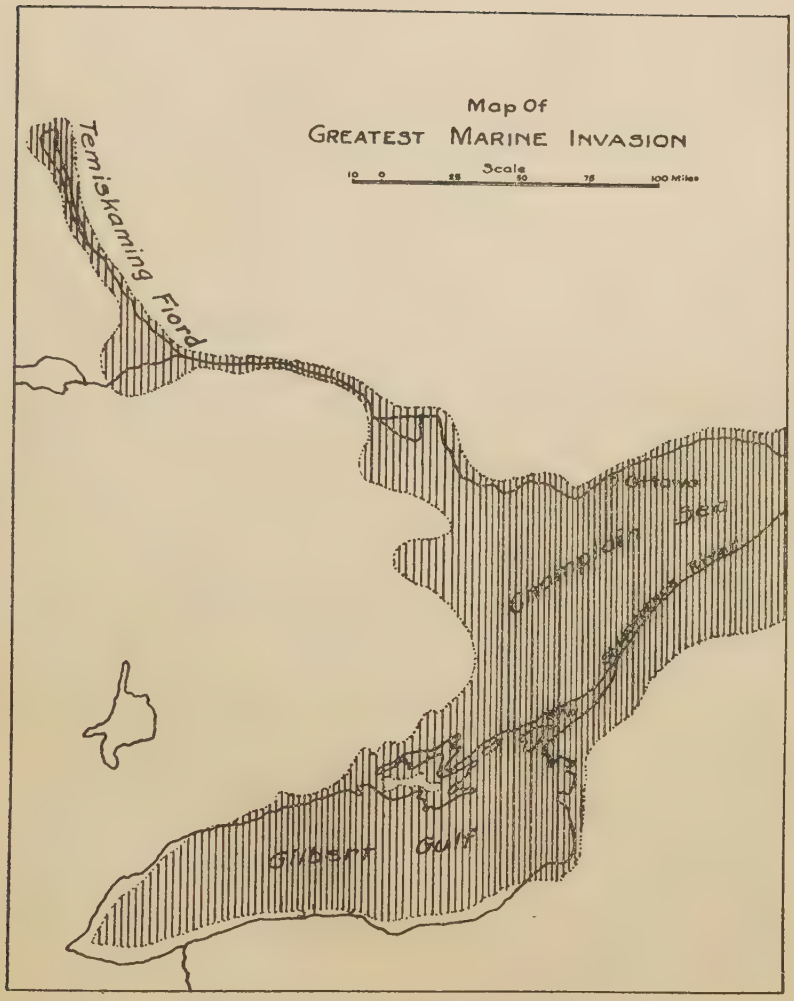
[1]U.S. Geol. Sur., Bull. 48, 1888.



12. Map of Maximum Marine Invasion

Marine Stages in Eastern Ontario

As the climate grew milder the water removed from the ocean to form glaciers was returned to it and the level rose to correspond. All the lower part of eastern Ontario was flooded by what has been called the Champlain sea, really an extension of the Gulf of St. Lawrence. This is proved by many beds of clay, sand, and gravel charged with shells of *Macoma*, *Saxicava*, *Mytilus*, and other molluscs, though no continuous beach has yet been mapped across Ontario. The upper limit of the marine invasion has been determined in some places and it is certain that it rises toward the north.[1] East of Brockville there is a beach with shells of *Macoma* rising 331 feet above present sea level, and marine shells occur also in the town itself; but west of Brockville none have been found. Fairchild has recorded higher marine terraces near Clayton in the state of New York, and has given the name Gilbert gulf to the extension of the marine water level into the Ontario basin.[2]

Though no marine beaches have been traced past Brockville, it is almost certain that shore forms in the Bay of Quinté region represent the westward extension of these levels. In the state of New York such a shore occurs from point to point as far west as Oswego, where it is lost beneath Lake Ontario. On the north side of the lake a good beach hand-levelled at Waupoos, near the east end of the county of Prince Edward, is at 340 feet. The best beach near Trenton, as already mentioned, stands at 324 feet, and other beaches occur at Brighton, Colborne, Cobourg, and Port Granby five miles east of Newcastle. At the last point there is a terrace 274 feet above the sea, or 28 above Lake Ontario. Beyond Port Granby it has not been found,

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[1]Marine and Freshwater Beaches of Ont., Bull. Geol. Soc. Am., Vol. 12, 1901, pp. 129-146; also Late Pleistocene Oscillations of Sea Level, Johnston, Geol. Sur. Can., Mus. Bull. 24; and Champlain Sea in L. Ont. Basin, Mather, Jour. Geol., Vol. XXV, 1917, pp. 542-554.

[2]Bull. Geol. Soc. Am., Vol. 17, 1907, p. 112; also N.Y. State Bull., Nos. 209-10, 1919.

probably because it has been cut away by the waves of the present lake.[1]

From Waupoos to Port Granby there is an average decline of two feet per mile in the direction of tilt, and if this continued toward the southwest the old shore would sink beneath Lake Ontario a little west of Whitby. At the same rate of decline the ancient gulf would end about ten miles east of Hamilton. As no fossils of any kind have been found on the shores of Gilbert gulf, while sea shells are widely distributed and often very numerous eastward from Brockville, one may conclude that its waters were kept fresh by the inflow of Niagara river.

The changes of water level succeeding Admiralty lake have been attributed, thus far, to the continuous melting of the ice sheets restoring water to the sea. In reality, as Mather[2] and Johnston[3] have suggested, there was a complication due to the northward rise of the land brought about by relief from the load of ice. As the sea was filling up by the melting of the ice there was also a tendency for the whole region to rise higher above sea level. Probably the rise of the land lagged considerably behind the removal of the load; so that the sea had time to leave its mark in shore deposits and high level beaches before the general elevation caught up with it.

Ultimately, the Thousand Islands region rose above the level of the sea, and Gilbert gulf was replaced by Lake Ontario, the change being probably a gradual one. The northeastward rise continued till the lake stood 246 feet above the sea; but within historic times there appears to have been no further elevation.

The outlet rose faster than the southwest end of the lake, so that all the rivers toward the west have their lower ends drowned, as illustrated by the depth of Niagara river near its mouth and as may be seen in the meanders occupied

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[1]Bur. Mines, Ont., Vol. 13, 1904, p. 238, etc.
[2]Jour. Geol., Vol. XXV, pp. 542-554.
[3]G.S.C., Bull. 24.

by dead water on the last two miles of the Humber. Probably, too, the deep water behind Toronto island and Burlington beach near Hamilton is due to the continued building up of beach materials as the water was backed up toward the west. There is a great similarity between the present Burlington bar cutting off Hamilton bay and the splendid bar of Lake Iroquois rising 116 feet above the present water level and cutting off a vanished Dundas bay of the ancient lake. Both have been caused by differential elevation that continued for thousands of years.

Life and Climate of the Marine Stage

Though the fresh water deposits of Gilbert gulf afford no evidence of life, the brackish and salt water beds farther east and north are very rich both in individuals and species. The marine forms include pelecypods, gastropods, sea acorns, starfish and sponges, the caplin and two other kinds of small fish, and seals, dolphins and whales. Concretions in the marine clay at Green's creek near Ottawa have supplied a few feathers of unknown birds and some bones of a duck, as well as a chipmunk and several beetles, the latter extinct according to Dr. Scudder.

Almost all of the aquatic animals discovered in the marine beds still survive in the Gulf of St. Lawrence, and suggest a cooler climate than that of eastern Ontario at present. This may be accounted for by supposing that the entrances to the enlarged Gulf of St. Lawrence were broadened and deepened to the north and south of Newfoundland, allowing easier access for ice floes and bergs than at present. So large a body of cold water as the Champlain sea probably had a chilling effect upon the climate of its shores.

A number of plants have been obtained, including sea weeds, marsh plants and several trees, such as poplars, yellow birch and sugar maple. All of the trees still live in the Ottawa valley, where most of the fossil species have been collected. Sir William Dawson believed that the plants indicate a somewhat cooler climate than that of Ottawa at present, but milder than that of Labrador.

The *Geology of Canada*,[1] Dawson's *Canadian Ice Age*,[2] and writings of Ami[3] and Johnston,[4] may be consulted as to the inhabitants of the Champlain sea in eastern Ontario. The lists include not only species from eastern Ontario, especially the Ottawa valley, but also animals and plants from Montreal and points on the lower St. Lawrence.

Relations of Marine Levels in Eastern Canada

Dawson explained most of the glacial phenomena of Ontario and Quebec by assuming that the watershed between the St. Lawrence system and Hudson bay was lowered sufficiently to open a broad strait between the Champlain sea and an enlarged Hudson bay or sea. Through this channel he supposed that a powerful current like that off the coast of Labrador swept icebergs and floe ice from the Arctic regions, lowering the temperatures of all eastern Canada. He believed that the boulder clay of the Pleistocene was formed by floating ice and not by a Labrador ice sheet moving toward the south. This view is no longer held by any glacial geologist; yet it is of interest to enquire into the extent of the marine invasion to the north and the south of the watershed.

It is known that Hudson and James bays extended much farther south in late Pleistocene times than at present. Marine shells have been reported 450 feet above the sea and 150 miles southwest of James bay at the forks of the Albany and Kenogami rivers;[5] and also on Soweska river, a branch of the Missanabie river, 128 miles southwest of James bay.[6] None have been found, however, directly south of the bay; and it is probable that the ice withdrew from the southwest side of Hudson bay sooner than from the James bay region, allowing a narrow tongue of sea to come

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[1]G.S.C., 1863, pp. 916, etc.

[2]Can. Ice Age, 1893, pp. 18, etc.

[3]Contributions to Pal. of Post-pliocene, Ottawa Naturalist, Vol. XI, pp. 22-26.

[4]G.S.C., Mem., 101, pp. 16-34.

[5]Robert Bell, G.S.C., Vol. 1871-2, p. 112.

[6]J. Mackintosh Bell, Bur. Mines, Ont., 13th Rep., Part 1, p. 164.

in between the watershed and the ice front. No gravel beaches nor shore cliffs have been described in the region and wave action was apparently only slight.

It is generally held that the sea rose to 500 feet on the southwest side of Hudson bay; while Low gives its elevation at one place on the east side as 710 feet, and mentions the interesting fact that seals live in Seal lake nearly 800 feet above the sea and nearly 100 miles inland.[1] They probably reached the lake when the sea was at its highest level. It is possible that the sea encroached even farther on the land, since the highest marine beaches usually do not enclose shells. Until careful study has been given to the Pleistocene features of the Hudson bay slope the exact southern limit of marine invasion will not be known. If we assume that it reached the 500 feet level, White's Relief Map of the Dominion shows its most southerly point to be on Abitibi river about 130 miles northwest of the head of Lake Timiskaming.

Turning now to sea levels south of the Hudson bay watershed, we find that here also there are no definite shore lines, though there is reason to believe that marine waters reached much above the highest known deposits containing sea shells. De Geer and Johnston report a beach at Kingsmere near Ottawa at 690 feet, as mentioned before, and not far off Johnston has estimated the northward rise of one of the beaches as amounting to three feet per mile. This rate of deformation is more rapid than the two feet per mile found farther southwest near Lake Ontario, but is probably correct, since all the old beaches of the region rise more rapidly toward the northeast or north.

We may apply this rate of rise to the fiord-like bay reaching to the head of Lake Timiskaming. The distance north of the parallel of Kingsmere is 133 miles, which implies a rise of 399 feet. If this is added to the height of the beach at Kingsmere, 690 feet, it gives a sea level of 1,089 feet at

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[1]G.S.C., Vol. IX, 1896, p. 13 L and p. 42 L.

the most northerly point reached by an arm of the Champlain sea.

Now the watershed between Lake Timiskaming and Lake Abitibi is 935 or 940 feet above sea level, and the pass used by the T. and N. O. railway, some distance to the west, is at 1,044 feet.

From these figures it is evident that if no obstruction intervened, the broad strait suggested by Dawson must have been a reality. However, the discrepancy between the highest probable sea levels on the two sides of the watershed is so great that the northern invasion of the sea must have occurred much later than the southern one, in fact after the whole region had risen some hundreds of feet because of the relief from the load of ice. The southern side was the first to be unloaded and had already risen greatly before the northern side began to be set free.

It may be considered certain, then, that the Hudson bay watershed was never submerged and that no strait turned Quebec and Labrador into an island. The isthmus connecting northern Quebec and northern Ontario was 130 miles wide at its narrowest point.

Faunal Relations in the Lakes of Ontario

There seems to have been no break in the continuity of the fresh water fauna between Lake Iroquois and Lake Ontario, in spite of the marine stage which has just been mentioned. Lake Iroquois inherited its inhabitants, through some short lived intervening stages, from Lake Warren, which had its outlet into the Mississippi. Ultimately, then, Lake Ontario has obtained its fauna from the Mississippi waters, which escaped glaciation because of their position south of the margin of the ice sheets during their different advances. Apparently some of the Mississippi forms, perhaps for climatic reasons, failed to reach Lake Ontario, or else have found conditions unfavourable in later times, since a number of the Mississippi shellfish which lived in the Niagara

river when the Falls was at the Whirlpool are not known from Lake Ontario.

From the complicated history of the Great Lakes and their predecessors which has been outlined in this paper it will be seen that all of our Ontario Lakes, small and large, even to the north of the Hudson Bay watershed, have in one way or another had connections, and that ultimately the fluvial and lacustral faunas inhabiting them have come from the Mississippi waters, sometimes, however, in very roundabout ways. The Mississippi and its tributaries supplied a harbour of refuge when the northern part of the continent was ice-covered and lifeless, and colonized the lakes and rivers which arose after the melting of the ice sheets. If the ice had reached the Gulf of Mexico, so that no place of refuge remained for fresh water life, our lake and river fauna must have been meagre indeed. Anadromous forms coming from the sea, like the salmon which once spawned in the streams tributary to Lake Ontario, might in time have become "land locked" varieties or species, but I am not aware that this has been the case. Probably the incoming of the Mississippi fauna filled all the positions available.

The connection between the waters of the Great Lakes and Rainy Lake, Lake of the Woods and the Manitoba Lakes appears to be limited to the drainage of Lake Agassiz and of Lake Warren, etc., into the Mississippi. Here the mode of communication seems very devious, but sufficient in the lapse of hundreds or thousands of years to account for the identical or closely related species found in these distinct drainage systems.

There are a few cases of lakes on the northern watershed having two outlets, one to the Great Lakes, the other to James bay; but I am not aware of any two-outlet lakes on the height of land between the Great Lakes and Seine river to connect up the St. Lawrence drainage system with that of Nelson river, so that the connections with the Mississippi must be considered to account for the species common

to the two drainage systems, unless some mode of transport over land or through the air can be assumed.

Temperatures in Deep Lakes

A comparison of the fauna of the glacial lakes, so far as known, with that of our present lakes which have no permanent ice on their shores, shows little difference between them. Practically all of the species still live in our waters. This comes as a surprise when one recalls that the early lakes had a vast sheet of ice to the north forming their shores for many miles. Why should these subarctic waters be inhabited by the same species as live in our temperate climate lakes? The presence of caribou and fur clothed elephants and of black spruce and tamarack on the shores of Lake Iroquois suggests a colder land climate than the present at Hamilton and Toronto, as one might expect when one-third of the continent was still covered with ice; but the aquatic life shows no such difference.

To explain this requires a consideration of the peculiar physical properties of water. Unlike other liquids water does not contract uniformly as the temperature is lowered to the point of consolidation. After contracting steadily to 39.2 degrees (Fahr.) water begins to expand and this continues for seven degrees to the freezing point, when it changes to the solid state and suddenly expands about one eighth of its volume. Other liquids contract all the way and congeal to a solid which is heavier than the liquid. For this reason cold water floats on warmer water and ice floats on cold water. If water followed the usual law when cooled below 39°.2 (4° Cent.) it would sink to the bottom instead of remaining at the surface, and at length the whole body of water would reach the freezing point of 32° (0° Cent.), when ice would be formed, and being heavier than water, would accumulate at the bottom. During a long winter the whole lake would be transformed into a solid block of ice, in which no life could survive. Some of the surface ice would thaw in summer, but in deep lakes the lower parts would be perpetually frozen.

The anomalous physical property of water just mentioned permits the lake to cool to the point of greatest density, after which further cooling causes the water to grow lighter so that it remains at the surface and is finally changed into ice, which floats and forms a non-conducting protection to the water beneath. The importance of this for the inhabitants of lakes is manifest. With winters as long and cold as those of our region the whole volume of water in a lake must reach the temperature of greatest density, and in deep lakes the lower portions must remain at this temperature all the year round.

Temperatures at Different Depths in the Lakes

Through the kindness of Dr. W. A. Clemens the following data have been collected on this subject:[1]

Lake Ontario—W. A. Clemens, Oct. 3, 1922.

Depth	*Temperature*
Surface	67.6 Fahr.
10 fathoms	60.4 "
20 fathoms	47.0 "
30 fathoms	40.6 "
50 fathoms	39.2 "
62 fathoms (Bottom)	39.2 "

These records were obtained at a point about half way between Toronto and the mouth of the Niagara River.

Lake Erie—W. A. Clemens, off Merlin, Ont., Aug. 3, 1920 (bottom temperature), 5 and 6.6 fathoms 52°.5.

Lake St. Clair—Prof. J. E. Reighard—A Biological Examination of Lake St. Clair, Sept., 1893. 64°.4 to 69°.8 (little difference between bottom and top—not more than 1°).

Georgian Bay—A. T. Drummond, Can. Rec. Sc., Vol. IV, pp. 77-85, and Vol. V, pp. 13-19:

Aug. 20, 1886, Bottom 31 fathoms 39°.5
Bottom 47 fathoms 38°.25

[1]As most of the data are in the form of Fahrenheit degrees, with depths in fathoms, it has been decided to recast the others to make them comparable.

Georgian Bay (*Continued*)—Bottom 42 fathoms 37°.75
July 10, 1889, Bottom 70 fathoms 38°.75
Sept. 8, 1889, Bottom 63 fathoms 39°
Surface varied from 59°.75 to 68° Fahr.

July 27, 1888,	Surface	60°.2
	10 fathoms	45°.7
	20 fathoms	41°.4
	35 fathoms	41°
	66 fathoms	39°.5

In Parry Sound Harbour, 1890:

May 2,	Surface	36°.2
	Bottom, 62 fathoms	35°.7
Aug. 23,	Surface	61°.7
	Bottom, 48 fathoms	39°.2
Oct. 15,	Surface	53°.5
	Bottom, 57 fathoms	39°

Lake Huron—Dr. Walter Koelz,[1] Department of Zoology, Univ. of Mich.:

Sept. 12, 1917,	Off Alpena,	65 fathoms	Bottom 39°.2
" 17,	Off Alpena,	15 fathoms	Bottom 57°.2
" 18,	Off Alpena,	60 fathoms	Bottom 39°.2
" 29,	Cheboygan,	35 fathoms	Bottom 39°.2
" 13, 1919,	Alpena		Surface 60°.1
" 13,	Alpena	35 fathoms	Bottom 41°.7

Lake Michigan—Prof. H. B. Ward—Biol. Exam. in Traverse Bay Region—gives 98 records of surface and bottom temperatures taken during August, 1894:

Highest Surface Temp., Aug. 15		70°
Bottom Temp., Aug. 15,	6.2 fathoms	68°
Lowest Bottom Temp., Aug. 16,	61.3 fathoms	39°.5
Lowest Bottom Temp., Aug. 18,	72.5 fathoms	39°.5
Surface Temp. on both dates		64°.9

Lake Superior—Dr. Walter Koelz:

Aug. 24, 1921, Off Ontonagon	Surface	64°.6
Aug. 24, 1921, Off Ontonagon	60 fathoms	39°.2
Aug. 25, 1921, Off Ontonagon	34 fathoms	41°

[1]Kind acknowledgment is hereby made to Dr. Koelz for permission to publish these records.

Drummond in Can. Rec. Sc., Vol. IV, pp. 78, states that Hind found the surface of Lake Superior on 30th July, at noon, as low as 39°.5 fifty miles from land.

Lake Nipigon—Dr. W. A. Clemens:

July 9, 1921	Surface	71°.6
July 9, 1921	23.2 fathoms	39°.5

(At deepest point, 67 fathoms, temp. probably would be 39°.2)

Aug. 29	Surface	62°.8
Aug. 29	45 fathoms	40°.1

(At deepest point, 67 fathoms, temp. probably would be 39°.2)

It will be seen that the data recorded are very unequally distributed, and it is probable that the bottom temperatures given by Drummond for Georgian bay and Lake Huron, reaching as low as 37°.75 and 35°.7 Fahr. are an error and should not be lower than the point of greatest density, 39°.2 (4° Cent.), or making correction for the expansion of mercury at a depth of 60 fathoms, 38°.5 Fahr.

From the tables just given, it will be seen that the temperatures of deep water in the Great Lakes are about 39°.2, as might be expected in a region having cold winters. With reference to Lake Superior it may be mentioned that the present writer found a temperature of 40° at the surface near the north shore in July, 1899, and that Professor Ramsay Wright states that the temperature has been observed to be 39° Fahr. (=4° Cent.).[1] Shallow lakes, such as Erie and St. Clair, no doubt get above this temperature in summer, but we must think of our deep water fish as living most of their lives in water constantly at 39°.2 (4° Cent.), though they may come up to shallower and warmer levels to spawn.

Toward the close of the ice age, when the glacial lakes came into existence, it is probable that their waters also were at the temperature of greatest density, and that the salmon trout and whitefish would find conditions as con-

[1]Rep. Ont. Game and Fish Commission, 1892, p. 425.

genial as in the cold depths of Lake Ontario or Lake Huron or Superior at present. The climate of these deep lakes may not have varied appreciably during the thousands of years since their basins were freed from ice; though the climate of their shores must have changed from subarctic, suitable for the reindeer and the hairy mastodon, to the present temperate conditions.

Nevertheless, there are difficulties in accounting for the deep water fauna, since all the basins were filled with ice and the Mississippi south of the glaciated region has no lakes at 39°.2 in which the deep water fish could take refuge. It may be, however, that the Mississippi of glacial times had much colder water, most of it derived directly from the melting ice front, in which they found themselves at home in spite of its shallowness. The Mississippi must have been muddy, or at least milky, during the many thousands of years when it was draining the glaciers. Whether the animals of the clear lakes could accommodate themselves to muddy river water is a point for biologists to settle. The fauna specialized for the deep, clear, cold water of the Great Lakes must have found the conditions in the Mississippi much less favourable than the shallow water species.

Time Relationships as Shown by Niagara

It is of interest from several points of view to obtain an estimate of the length of time required for the various events outlined in the history of the Great Lakes region. The chronometer usually relied on to measure the time since the Glacial period is the cutting back of the gorge of Niagara from Queenston heights to the present falls, a distance of nearly seven miles. If the length of the gorge is known, and the rate of recession can be estimated, it seems a simple matter to determine the time since Niagara began its work, *i.e.*, since the ice retreated far enough to allow the river to plunge over the escarpment. The length is known and the rate of retreat of the falls since the first accurate survey, in

1842, has been estimated by Spencer at 4.2 feet per annum[1] and by Taylor at 4.5 feet per annum.[2] By simple division the result is 8,000 or 9,000 years as a round number; but unfortunately it cannot be assumed that the recession has been uniform, since it is known that the volume of water passing over the falls has varied greatly. At times the volume may have been greater than at present, since the natural drainage of the area was augmented by rapid melting of the ice sheet; but at other times the waters of the upper lakes were drawn off by lower outlets, through the Trent and the Mattawa channels, leaving only the drainage of the Erie basin, probably 15 per cent. of the existing flow. There were, then, two periods when the amount of water was seriously cut down so that the attacking power of the falls was greatly reduced. The times of increased and diminished flow, with other variations in conditions of less importance, are more or less completely recorded in the changing width of the ravine below the falls. The features shown in the gorge may be correlated with the known history of the lakes and their drainage channels, and thus a time table may be worked out for the cutting of its wider and narrower parts. This was attempted by Spencer, who studied the problem carefully and concluded that the total time consumed was 39,000 years.[3] Taylor has repeated the calculation with more complete knowledge of the history of the lakes and makes a less positive statement of the age of the falls which he thinks lies between 20,000 and 35,000 years.[4] He divides the work into five stages, during two of which, when Lake Algonquin drained through the Trent valley, and when the Nipissing Great Lakes had their outlet through the Mattawa valley, the recession must have been slow because of the small amount of water passing over the falls. The most certain part of the process is naturally the latest, since present conditions have been operative; and he makes the

[1]Falls of Niagara, G.S.C., p. 342.

[2]Niagara Folio, U.S. Geol. Sur., No. 190, p. 23, 1913.

[3]Evolution of the Falls of Niagara.

[4]Folio 190, U.S. Geol. Sur., p. 24.

13. Dutch Church in 1900

14. Dutch Church in 1915

time required for the excavation of the Upper Great Gorge from 3,000 to 3,500 years.

In the two time-estimates just given, the amount of water in the Niagara river determines the rate at which the falls has cut its way back from Queenston Heights, and this amount is estimated in accordance with the areas draining into the river. When the waters of the upper lakes flowed over the falls the work went on as rapidly as at present; but when the supply came from the Erie basin only it was very much slower. The excavation of the narrow parts of the gorge required probably four times as long a time as the broad ones.

It will be noted that the Niagara chronology is drawn from the history of the outlet rivers of the upper lakes and provides a rough means of estimating the length of the different stages of these lakes, but has no reference to the bodies of water occupying successively the Ontario basin. After the water in this basin had fallen low enough to set at work the machinery of the falls the two systems followed separate lines of development, and it is not easy to correlate the events in the upper lake basins with those in the lower one.

Time Relations of Events in the Ontario Basin

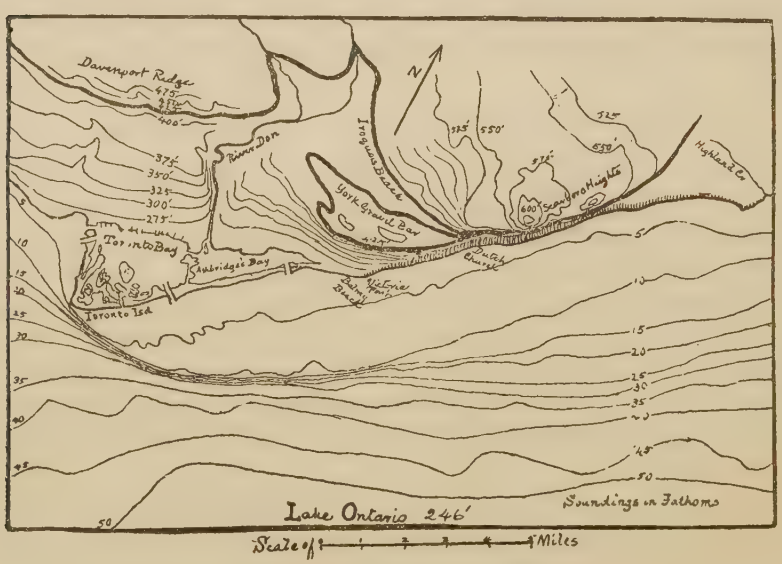
The Ontario basin began to be freed from ice during the existence of Lake Warren, but the falls did not commence its work until the outlet past Rome into the Hudson was opened and probably not until the water fell to the early level of Lake Iroquois, which at its west end may have been as low as the present Lake Ontario, giving a much greater drop than that of Niagara as we know it. It is possible, however, that there were two or three separate falls over as many hard layers in the succession of rocks during the early parts of its existence.

If one accepts the chronology of Niagara just given, the whole of the bodies of water mentioned in former pages as occupying the basin at different stages must have run

their course in from 20,000 to 35,000 or possibly 39,000 years. How is the time to be divided among them?

Two of these bodies of water, Lake Iroquois and Lake Ontario, were much alike in area and have beaches of about the same maturity. The work performed on their shores shows that both must have been long lived; while the intervening stages, including the marine episode, are represented by much less perfectly formed beaches, suggesting a shorter time for wave action. It should be added, however, that the shores of Admiralty lake, which came just before the marine invasion, are probably mostly submerged under Lake Ontario and so out of reach.

Lake Ontario is still at work and it is possible to measure the results of its wave action. For this purpose the recession of the cliffs of glacial and interglacial deposits at Scarborough Heights east of Toronto is well suited. The first accurate survey of Scarborough was made in 1862 and the distance of the cliffs from seventeen fixed points was remeasured in 1912. Some of these lines came out at ravines which were



15. Map of Shore and Island at Toronto

being rapidly cut back by streams and were left out of the computation, but the average of thirteen which seemed normal gives a recession of 81 feet in the fifty years.[1] This works out to 1.62 feet per annum. Soundings show that shallow water extends for about 13,000 feet from the shore before the more rapid slope of the lake bottom toward greater depths; and it is inferred that the cliffs once reached this point. At the present rate of destruction a recession of 13,000 feet implies about 8,000 years.

A computation of the time required to build Toronto island at the present rate of movement of sand along the shore suggests the same age, but the problem is more complicated, and the results much less certain.

Spencer strongly opposed this estimate and held that Lake Ontario has existed for only 3,500 years.[2] So far as one can judge from his rather obscure statement, his reason for taking this as the age of the lake is that 3,500 years ago the northeast angle of Lake Huron was tilted, turning more water into the St. Lawrence drainage. By this he means, no doubt, the closing of the North Bay outlet of the Nipissing Great Lakes, inaugurating the present régime for the upper lakes. Taylor estimates the time during which the upper lakes have emptied through Niagara river at 3,000 to 3,500 years, as mentioned before, confirming Spencer's view which one may agree is correct; but it is not apparent why this event in connection with the upper lakes should fix the age of Lake Ontario. There is good reason to believe that the basin has been greatly tilted since Gilbert gulf came to an end, as shown by the depth of the channel of the Niagara and by the 78 feet of water behind Burlington beach. No definite reason has been mentioned by Spencer why Lake Ontario should not have begun during the lifetime of the Nipissing Great Lakes. They were entirely post-glacial and their outlet through the Mattawa valley must have reached the Ottawa after the marine waters had greatly fallen, since

[1]Compte-Rendu, 12th Geol. Congress, Toronto, 1913, pp. 435-449.
[2]Am. Jour. Sc., Vol. LXIII, No. 257, 1917, p. 360.

the point of junction is now only 488 feet above sea level. Mattawa is fifty miles north of the parallel of Kingsmere, and with a rise of three feet per mile would be 150 feet above it when the Champlain sea reached its highest level. The Kingsmere beach is at 690 feet, so that the highest stage of the sea at Mattawa must have been 840 feet, implying a sinking of 352 feet before the Nipissing Great Lakes ceased to exist. Mattawa is 150 miles north of the parallel of the Thousand Islands, and it is probable that while the outlet of Lake Ontario rose 246 feet to its present level Mattawa rose at least 488 feet, allowing for differential elevation toward the north, which would be only 1.6 feet per mile, about one half of the rate worked out for the highest beaches.

As the Iroquois shore is about as mature as the present Ontario shore one may assume that the two lakes lasted about the same length of time. If we suppose them equal in this respect and take Spencer's estimate of 3,500 years as the age of each of them, only 7,000 years are accounted for out of the 20,000 to 39,000 years provided by the Niagara chronology. What happened during the other 13,000 or 32,000 years? Was the marine episode with its feebly developed beaches four times as long as the Iroquois or Ontario time? This seems highly improbable, and the natural conclusion is that Ontario has lasted at least 8,000 years, and that it was for a long time contemporary with the Nipissing Great Lakes.

From the previous discussion of the correlation of events in the upper lakes region with those in the Ontario basin, it appears that during at least part of the time when the Trent outlet was in operation the water in the Ontario basin was at its lowest level, that of Admiralty lake; and that Lake Ontario was in existence and the marine waters had sunk 350 feet when the upper lakes were drained by the Mattawa valley.

It does not appear, however, that the duration of Lake Iroquois or of the marine stage or of Lake Ontario can be exactly placed with reference to Lake Algonquin and the Nipissing Great Lakes. Lake Algonquin certainly lasted

long after Lake Iroquois had ceased to exist, and, on the other hand, Lake Ontario, which began during the life time of the Nipissing Great Lakes, has long survived them. Probably Lake Ojibway, north of the divide, was a contemporary of the Nipissing Great Lakes for a part of their history, but came to an end long before they were transformed, by the northward rise of their outlet, into the present upper lakes.

Correlation Table

From the foregoing account of the lakes and arms of the sea which have occupied parts of the present St. Lawrence hydrographic region, it is evident that the relationships of the successive bodies of water in the different basins are very complicated. The following table is intended to make these relationships more clear:

Years ago	In the Ontario Basin	Upper Lake Basins	Hudson Bay Slope	Eastern Ontario
35,000	Lake Warren	Lake Duluth, Lake Chicago and Lake Warren	Lake Agassiz	
30,000	.....	.....	.....	.....
25,000	Lake Lundy, Lake Dana, etc. Niagara Falls and Lake Iroquois begin	Lake Algonquin begins with St. Clair Outlet Trent Outlet into Lake Iroquois		
20,000	.....	.....	.....	.....
17,000	Lake Iroquois ends			
	Lake Frontenac Admiralty Lake	Trent Outlet into Admiralty Lake		Early (Low) Marine Stage
	Gilbert Gulf	St. Clair Outlet Nipissing Great Lakes begin, Mattawa Outlet	Lake Ojibway	Maximum Marine Stage
10,000	.....	.....	.....	.....
8,000	Lake Ontario begins	Two Outlet Stage	Marine Stage	Marine waters gradually retreat to Quebec
3,500		Upper Lakes begin		
0	.....	.....	.....	.....

In the table just given the estimates of time are more accurate as they approach the present. That the Upper Lakes, Superior, Michigan, and Huron, began 3,500 years ago is fairly certain from the length of time required by Niagara to cut the upper great gorge. That Ontario began 8,000 years ago is made probable from the rate of wave erosion at Scarborough heights; but that Gilbert gulf, Admiralty lake and Lake Frontenac required altogether 9,000 years is merely a guess. The beginning of Niagara Falls and of Lake Iroquois is put at 25,000 years ago, while the various computations drawn from the Niagara gorge give from 20,000 to 39,000 years.

The dates of the earlier lakes are, of course, still less certain. Lake Agassiz may have begun 45,000 years ago if Spencer's estimate of 39,000 years for the work of Niagara is correct. On the other hand, Warren Upham suggests that 8,000 years are sufficient time to allow since the ice began to disappear from the Winnipeg region and that Lake Agassiz lasted only 1,000 or 1,500 years.[1]

It may be that the late glacial and post-glacial chronology of eastern America will ultimately be put on an exact basis through the actual counting of the annual layers of clay deposited during the retreat of the ice and since that time, as DeGeer and his assistants have done in Sweden. Baron DeGeer with two assistants undertook last year to measure portions of the stratified glacial clays of eastern Canada and the United States for comparison with the results obtained in Sweden, and apparently they have been successful in correlating part of the American post-glacial record with that of Europe, though the work is not much more than begun.[2]

Connections Between the Lakes

It may be useful to summarize the connecting links in space and time between the various lakes referred to above,

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[1]Glacial Lake Agassiz, U.S. Mon. XXV, pp. 238-244.

[2]Petermanns Mitteilungen, 67, 1921, June-July, p. 124.

so as to show in brief form the possible migrations of the fresh water fauna.

Lake Agassiz was probably connected with Lakes Duluth, Chicago, and Warren *viâ* the Mississippi, since all of them drained into that river. It is possible, however, that Lake Agassiz came to an end before the other lakes began.

Lakes Duluth, Chicago, and Warren became connected, as the ice lobes retreated northwards, and formed Lake Algonquin, which merged into the Nipissing Great Lakes, which at length passed into Lakes Superior, Michigan, and Huron. Lake Algonquin drained into Lake Iroquois *viâ* Niagara and Algonquin rivers (Trent valley), and later into Admiralty lake during the early low stage of sea level when Algonquin river extended down to what is now the Bay of Quinté. Bays of Lake Algonquin extended across the Hudson bay watershed at three cols as the ice retreated and thus connected with Lake Ojibway and ultimately with Abitibi and other lakes of northern Ontario. It is probable that Lake Ojibway drained for a time into the Ottawa and thus into the Champlain Sea.

The Nipissing Great Lakes drained in part through the Mattawa outlet into the Ottawa valley, then occupied by the sea, and in part *viâ* Niagara into Lake Ontario.

Lake Warren merged through various stages into Lake Iroquois, which drained through the Mohawk valley into the Hudson valley, then occupied by the sea. Lake Iroquois sank into Lake Frontenac, which was lowered to the Admiralty lake, which rose to correspond to the rising sea level and merged into Gilbert gulf, the water remaining fresh although connected with the Champlain sea, an expansion of the Gulf of St. Lawrence. Gilbert gulf passed gradually into Lake Ontario, which began just above sea level as the land rose, so that the St. Lawrence river was at first very short but grew longer as the rise of the land continued until the sea level became stationary at Quebec. Anadromous fish must have slowly adjusted their instincts to the lengthening of the river.

The Upper Lakes have had connections, often very long

and roundabout, with the Gulf of Mexico *viâ* the Mississippi; with the Atlantic *viâ* Algonquin river, Lake Iroquois, the Iri-Mohawk river, and the Hudson channel; and with the Gulf of St. Lawrence *viâ* the Mattawa outlet and the Champlain sea. None of these routes presented serious impediments such as important vertical falls. A sea salmon could have made its way up any one of the three routes. At present the falls of Niagara form an impassable barrier to any ascent from Lake Ontario or the sea, but a few thousand years ago there was much less difficulty in ascending to the Upper Lakes by the Ottawa and Mattawa valleys. The sea, probably somewhat brackish, reached as far north as the Mattawa river, now 488 feet above the sea level. Above this the climb to Lake Nipissing is only 154 feet including rapids but no important falls. Any fish with good swimming powers could have made the ascent.

Pleistocene Changes in the Life of the Region

As a sequel to the physical history of the Great Lakes region one may consider briefly the relations of its flora and fauna. Unfortunately the evidence as to the former plants and animals is very fragmentary.

In the account of the different glacial and post-glacial lakes, lists have been given of the species found in their shore deposits. All appear to be still living. The most frequent fossils are naturally shellfish and except in a few cases they still survive in the modern lakes. The few exceptions are of Mississippi molluscs, which seem to have died out in these waters.

The largest flora and fauna of post-glacial age are found in the marine beds, especially in concretions from the Leda clay of Ottawa. So far as known, none of the dozen plants, which include a few trees, differ from species of the present flora. Of the marine fishes and mammals none are extinct, so far as one can judge from the fragmentary remains preserved. Shellfish are naturally the most frequent fossil forms. Dawson describes from Ottawa and Montreal

142 species, of which he believes only two or three are extinct,[1] though some others present varietal differences. On the other hand the only sponge mentioned no longer lives, and all the insects, four in number, are extinct, according to Dr. Scudder.

The marine beds were laid down probably between 17,000 and 3,500 years ago, so that specific changes in molluscs seem to require a longer time than that, while the more highly developed insects, with their rapid succession of generations, are more quickly modified.

The only other important Pleistocene flora and fauna for comparison with present day species are those of the Toronto interglacial beds;[2] from which 63 species of plants and 122 species of animals are on record.

Of the plants 35 are trees, and all but three or four still exist, the extinct ones including *Acer pleistocenicum*, *A. torontoniensis* and perhaps another maple, and *Gleditschia donensis*, as determined by Penhallow. All are closely related to modern trees, the maples being apparently ancestors of our sugar maple.

Among the 41 shellfish, all are still living in North America, but apparently eight belong to more southern waters than Lake Ontario. The 72 insects are extinct with two exceptions, according to Dr. Scudder, as one would expect from the fate of the much later insects of the marine time. The two or three fish remains are too fragmentary for us to be sure of their species; and the six mammals are known only from separate bones or horns or tusks. The elephants, of course, are extinct, and the horn determined as *cervalces* by Bensley may be looked on as extinct also. Whether the large bear, known only from one of the bones of the head, the red deer, the caribou, and the bison belong to living or extinct forms cannot yet be decided.

The Toronto interglacial formation probably dates back at least 500,000 years and the changes in the life of the

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[1]Can. Ice Age, p. 279.

[2]Geol. Congr., 1913, Guidebook No. 6, pp. 15-25.

region seem surprisingly small for so great a lapse of time. Apparently molluscs have the slowest rate of change and insects the most rapid; the mammals perhaps being modified almost equally rapidly.

While no older Pleistocene deposits are known from Ontario there is reason to believe that the Aftonian beds of Iowa are more ancient, since they occur between the Nebraskan and Kansan boulder clays and occupy the first of four interglacial intervals recognized in that state. If the Toronto formation comes about half way down in the Pleistocene, as seems probable, the Aftonian must be some hundreds of thousands of years older and its flora and fauna should be correspondingly more ancient in character. Among plants, pine, tamarack, oak, elm, ash, walnut, hickory, and sumac are reported, but unfortunately the species seem undetermined, so that one cannot be sure as to whether they are of still living forms or not. It may be observed that all of the genera except the walnut and the sumac are represented in the Toronto formation.

Among animals only mammals have been found, and these have been determined mostly from isolated bones, jaws, and tusks; though the remains are more complete than those found at Toronto. Calvin describes and figures remains of two or three species of horses, a camel, two ground sloths, cervalces, two mammoths, and one mastodon.[1] All the mammals are extinct and have left no North American descendants, unless cervalces is an ancestor of the moose.

It will be recalled that cervalces and either mammoth or mastodon occur in the Toronto formation, but that the other mammals may be of still living species. The number of extinct species of mammals is greatly increased in the older interglacial formation.

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[1]Aftonian Mammalian Fauna, Bull. Geol. Soc. Am., Vol. 20, pp. 341-356.

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